ADVANCED TEXT-BOOK

GEOLOGY

DESCRIPTIVE AND INDUSTRIAL

BY

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THIRD EDITION, REVISED AND ENLARGED

WILLIAM BLACKWOOD AND SONS
EDINBURGH AND LONDON
MDCCCLXI

PREFACE.

THIS Treatise, while intended as a sequel to the Author's "Introductory Text-Book," has been prepared throughout as a separate and independent work. The purpose of these Text-Books is briefly this: The *Introductory* is meant to exhibit an outline of Geology intelligible to beginners, and sufficient for those who wish to become acquainted merely with the leading facts of the science; the *Advanced*, on the other hand, presents the subject in detail, and is intended for senior pupils and those who desire to prosecute the study in its principles as well as deductions. Though thus prepared on the same plan, and the one but an extension and development of the other, they are both independent elementary works, and may be taken separately or in sequence, according to the progress and purpose of the student. This much may be said, that he who has mastered the Introductory will have nothing to unlearn when he comes to study the Advanced, while his acquisition of the science will have been rendered much more easy and agreeable. The Author has a strong conviction on this point. In teaching the construction of the steam-engine, for instance, the most natural course is to explain, in the first place, its more prominent features—its boiler, steam-pipe, cylinder, piston, crank, and fly-wheel; and when the learner has acquired a knowledge of the rela-

tions of these parts, and the force which sets them in motion, then to proceed to the more intricate connection of valves, condenser, hot-well, air-pump, eccentric rods, governor, and other complicated machinery. By adopting this course, no confusion is created in the mind of the learner; he is impressed with gradual and permanent convictions; has nothing to unlearn; and may at length proceed with some degree of confidence to estimate the power of the entire machine, as depending on the consumption of fuel, the elasticity of steam, the dimensions of the several parts, and the force lost through friction. So it is with every science: Let an outline be given of its leading features, that the beginner may arrive at some notion of its purport and bearings; let this be followed by the details; and the details by the higher reasonings and philosophy of its problems. Under this conviction these volumes have been prepared; and it will be a source of unmingled satisfaction to the Author to find his views corroborated by the experience of intelligent and competent teachers.

One word to those who may object that these Text-Books do not contain enough of the "hard facts" of the science. It had been an easy matter for the Author to have loaded his pages with minute mineral distinctions, enumeration of localities, and lists of fossil species; but had he done so, he could not have chosen a more effectual plan to disgust the learner and retard his progress. What he has aimed at was the production, not only of class-books for schools, but readable manuals for self-instruction—treatises that in their readableness might imbue the student with the spirit and methods of Geology, rather than cram him with its details, many of which, in the progressive state of the science, are merely temporary and provisional. Once furnished with proper methods, and imbued with the right spirit, the earnest

student has in general little difficulty with details—every acquisition of his own not only widening the basis of his knowledge, but increasing his power to master new difficulties as these may arise in the course of his onward progress. Still more to foster this spirit, the Author has endeavoured to write as he would have spoken to a junior companion in the field—hopefully and encouragingly, yet not disguising the real difficulties that lie in the way—treating the subject as one to which the humblest observer may contribute his mite, rather than attempting to propound authoritatively on problems, the satisfactory solution of which involves a much wider range of observation, and deeper and more exact research, than Geology as yet can boast of.

Yet another word: The Author requests his brother geologists who may glance over these pages to remember that they are not intended to contain an exposition of his own peculiar views, but rather to exhibit an elementary outline of the science as now established by the leading workers in Britain, France, Germany, and America. The main object has been to render the student such assistance as will enable him to proceed in the field as a practical observer, and to read with appreciation the higher treatises, special monographs, papers, and new discoveries of others. To further this object mention is made, at the end of each section, of the principal works devoted to the department in question; to have done more would have been to enter on the field of speculative geology—a subject that lies beyond the scope of an Educational Text-book.

GILMORE PLACE, EDINBURGH,
March 1856.

SECOND EDITION *Published March* 1859.

THIRD EDITION.

THIS Edition has been enlarged—*first*, to embrace whatever is new and important in the science; *second*, to afford space for additional illustration; and, *third*, to combine, as far as possible, the Principles with the Deductions of Geology. We reason our way to the Past through our knowledge of the Present, and our descriptions of former epochs become more intelligible and impressive when viewed through the medium of existing phenomena. For this purpose there has been inserted such notices of operations now in progress as seem to bear on the subjects under review—and this in subordinate type, and in such a form as not to interfere with the continuity of the original textual arrangement. On the whole, it has been the aim of the Author to improve rather than enlarge — to keep the volume abreast with the latest discoveries and advancing views of our leading Geologists, and yet to prevent it from exceeding the limits of a compendious Text-Book.

SEPTEMBER 1861.

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GEOLOGY.

I.

OBJECTS AND SCOPE OF GEOLOGICAL INQUIRY—INTRODUCTORY OUTLINE.

1. To describe the earth we inhabit, in all its varied aspects and relations—mineral, vegetable, and animal—is the object of Natural History. It must be evident, however, that a field so vast could not well be made the subject of systematic scrutiny without subdivision into departments; hence, the sciences of Geology, Geography, Botany, Zoology, and Chemistry—each of them susceptible of separate research, yet all of them connecting, aiding, and combining to form one great theme of human knowledge. Thus, the Geologist restricts himself more especially to a consideration of the rocky or mineral structure of the earth, the Geographer to its external or superficial conditions, the Botanist to its various vegetable families, the Zoologist to its animal life, and the Chemist to the elementary composition of all its substances, whether mineral, vegetable, or animal. Though labouring in this manner in separate departments, the one is materially assisted by the investigations of the other: indeed, there can be no true knowledge of any one branch of natural science without some acquaintance with the whole. As in nature, so in man's interpretation, all should blend into one harmonious yet dependent system; and he who has the widest range of knowledge will best know how to avoid error and inconsistency in his own peculiar field of research. The student is thus warned, at the threshold, of the connections of his science, that he may under-

came fresh and glowing from the hand of the Creator. As a legitimate cultivator of natural science, the geologist bases his deductions on numerous and well-observed facts; observes, collects, and arranges with scrupulous care; and by such means proceeds from phenomena that are obvious and taking place around him, to the explanation of those that are more remote and less apparent. His object is to unfold the history of our globe as revealed in the composition and arrangement of the rocky crust which is patent to his investigation, not to invent theories or frame hypotheses respecting the origin of matter or the development of life—themes which may ever lie beyond the comprehension of created intelligence.

10. In reading aright the facts and phenomena which present themselves to his observation, the task of the geologist is often a perplexing—always an arduous one, and one requiring a vast amount of research and collateral information. To account, for example, for the aggregation and position of many rock-masses, he requires to be acquainted with the principles of mechanics; to treat of their composition and formation, the aid of chemistry must be frequently called in; to describe and classify the remains of plants and animals, he must have recourse to botany and zoology; while, generally speaking, there are many of his problems, for the successful solution of which the assistance of almost every branch of natural science is necessary. It does not follow, however, that he is to make these minute researches for himself: it is enough for his purpose to be able to apply the deductions of the chemist, botanist, and zoologist to the solution of the particular problem before him; in other words, to be able to appreciate their geological bearings, and arrive at the right interpretation of the phenomena of which they form a part. In doing all this the earnest student will find the pleasure of the result more than recompense for the labour incurred; and whether in collecting data among the hills and ravines, by the sea-cliffs or in the mine, or in arranging and drawing from these data the warranted conclusion, he will find Geology at once one of the most healthful and exhilarating, as it is intellectually one of the most fascinating and expanding of human pursuits.

Practical Bearings of the Science.

11. Nor is the science, in a *Practical* or *Industrial* point of view, of less importance to man. Deriving, as we do, all our metallic and mineral stores—our coal and iron, our gems and

precious metals—from the crust of the earth, it is of vast utility to be able to distinguish correctly between mineral substances, to determine in what positions they occur, and to say where they are, or are not, to be found. The miner cannot proceed a step in safety without the light of geological deduction; and though guided by observation long before the truths of the science assumed a technical aspect, yet do his operations proceed with precision and certainty only in proportion to the advancement of scientific generalisation. Again, the engineer in tunneling through hills, in cutting canals, excavating harbours, sinking wells, draining morasses, and the like, must, to do his work securely and with certainty, base in a great measure his calculations on the nature of the rocky materials to be passed through—information he can only obtain through the aid of geology. The architect also, in selecting his material, by attending to the formation and texture of the rock, and observing how it has been affected by the weather in the cliffs and ravines, may often avoid the use of a wasting and worthless building-stone; while his knowledge of geological succession will enable him to detect in different localities the same material. The farmer, in like manner, whose soils are either formed by the disintegration of the subjacent rocks, or are affected by their retentive or absorbent nature, may learn much useful information from the demonstrations of geology. The study of physical geography—that is, the study of the surface configuration of the earth, the distribution of land and sea, the altitude and extent of continents, and so forth, in so far as it bears on the dispersion and habitats of plants and animals, their adaptation to certain regions, and even touching the development and health of man himself—can only attain the character and position of a science, if treated in connection with the fundamental doctrines of geology. The artist and landscape-gardener may also reap substantial benefit from a study of the leading facts of the science; and though such a knowledge of itself will make neither artists nor landscape-gardeners, it will often prevent them from committing unpardonable outrages on the landscapes of nature. Such are a few of the more obvious practical or economic advantages of geology—a subject to which we will advert at greater length (CHAP. XX.) when the student is presumed to be able to apply its deductions.

12. To arrive at a rational history of the successive phases of the globe, is, we have said, the aim of theoretical geology; to discover and classify its mineral stores—to ascertain their position and determine their abundance, so as to make them available for the industrial purposes of life—is the task of the practical geolo-

gist. Combining its economic with its speculative bearings, Geology becomes a science of high and enduring interest, and one which must shortly take a place in every course of enlightened education. And, luckily for its progress, the objects of research, though often complicated and obscure, are scattered everywhere around us. Not a quarry by the wayside, not a railway-cutting through which we are carried, not a mountain-glen up which we climb, not a sea-cliff under which we wander, but furnishes, when duly observed, important lessons in geology. A hammer to detach specimens, and a bag to carry them in, a sketch-book to note unusual appearances, an observing eye, and a pair of willing limbs, are nearly all the young student requires for the field; and by inspection and comparison in some museum, and the diligent use of his text-book, he will very shortly be able to proceed in the study as a practical observer. Let him note every new and strange appearance, handle and preserve every specimen with which he is not familiar—throwing nothing aside until he has become acquainted with its nature; and thus, besides obtaining additional knowledge and facilitating his progress in the study, he will shortly acquire the invaluable power of prompt and accurate discrimination.

NOTE, RECAPITULATORY AND EXPLANATORY.

13. In the preceding chapter we have endeavoured to explain that the object of Geology is to investigate the rocky structure, and, through that structure, the history of the earth, in as far as its structural arrangement is accessible to human investigation. Combining all we know of this rocky structure, from the top of the highest mountain to the bottom of the deepest mine, it forms but an insignificant film of the four thousand miles which lie between the surface and centre of the globe. This film or outer portion is spoken of as the "crust of the globe" (*Erdrinde*, as the Germans term it), in contradistinction to the interior portions, of which we can know nothing by direct observation. Thin as this crust may appear, it is nevertheless the theatre of extensive, diversified, and ceaseless changes. Every change arising from the violence of the earthquake and volcano, every modification resulting from the waters that cover of course its surface, every operation dependent on atmospheric agency, as well as all that appertains to the development of vegetable and animal life, is

performed on or within this shell. It is thus at once the theatre of all geological change, and the index to all true geological history. By noting the composition of its rocks, their position and succession, the space over which they spread, and the fossils they contain, the geologist is enabled to indicate the condition and appearance of the world during former epochs—to speculate as to the former distribution of sea and land, the modifications of climate thereby occasioned, and the kind of vegetables and animals that successively peopled its surface. To arrive at a rational history of the successive phases of the globe, is the aim of theoretical geology; to discover and classify its mineral stores—to ascertain their position and determine their abundance, so as to make them available for the industrial purposes of life—is the task of the practical geologist. Combining its economic with its speculative bearings, Geology becomes a science of high and enduring interest, deserving the study of every cultivated mind, and the encouragement of every enlightened government.

14. As a department of Natural History, geology confers, as well as receives, important aid from all the co-relative branches of the science—more especially from Geography, Botany, Zoology, and Chemistry. For the solution of many of its more difficult problems, it also calls in the aid of Physical or Mathematical Science; while not a few of its reasonings are based on Meteorological and Astronomical considerations. It has been proposed by some to substitute the term *Geognosy* for that of *Geology*—geognosy (*gè*, the earth, and *gnosis*, knowledge) implying absolute knowledge; while geology refers more to our theoretical reasonings. The substitution, however, is rarely or ever adopted; and for all ordinary purposes geology has become the accepted designation. As thus defined, the science may be viewed in three great aspects,—Descriptive, Theoretical, and Practical; *Descriptive Geology* being that which restricts itself to a consideration of facts and appearances as presented in the rocky crust; *Theoretical*, that which attempts to account for the phenomena, and arrange them into a connected world-history; and *Practical*, that which, guided in its researches by the other two, treats of the mineral products of the globe, the methods of obtaining them, and their application to industrial or economic purposes.

15. As a main topic, geology may also be conveniently studied under the three sub-sciences—*Physical Geography*, *Mineralogy*, and *Palæontology*; the first, treating of the surface configuration of the globe as depending on geological influences; the second, restricting itself more especially to a consideration of the mineral substances which enter into the composition of the crust; and the

third (from *palaios*, ancient—*onta*, beings—and *logos*, reasoning), devoting itself exclusively to a consideration of the fossil plants and animals found in the rocky strata. Each of these sub-sciences can be studied intimately, and in detail, as separate departments; yet it must be seen at a glance that, without an acquaintance with all the three, there can be no true knowledge of geology. The terms *Physical Geology* and *Lithology* (*lithós*, a stone, and *logos*, reasoning) are frequently used as in contradistinction to *Palæontology* or *Organic Geology*—the former referring to the mere rock relations of the crust, the latter to the plants and animals imbedded therein. Hence we may treat of the *lithological* character of a formation without at all referring to its *palæontological* aspects. The term *Petralogy* (*petra*, a rock) was at one time used for Lithology, and *Oryctology* (*oryctos*, dug up) for Palæontology; but they are now very rarely employed. It has also been proposed to subdivide Palæontology into two branches —*Palæozoology* (*zoon*, an animal), or that which relates to fossil animals, and *Palæophytology* (*phyton*, a plant), or that which refers alone to fossil vegetation; but, for all practical purposes, the broader term Palæontology, which embraces all organic remains of whatever description, may still be advantageously retained.

16. For fuller explanations of these and other technical terms employed throughout this treatise, the student is referred to the appended Glossary; and should he desire still more detailed information, the Author's *Handbook of Geological Terms and Geology* may be consulted with advantage, as supplying many important particulars that obviously lie beyond the scope of a general Text-Book. And here it may be remarked, that these scientific terms, when once thoroughly comprehended, are quite as easily remembered as those derived from the language of every-day life; while, being chiefly compounds of Greek and Latin, they constitute a nomenclature distinctive of, and peculiar to, Geology, and are thus readily intelligible to the scholars of every country. There is nothing more perplexing than a multiplicity of local and provincial terms; and one can easily imagine the confusion and obstruction that would arise were every country and district adhering to its own vernacular instead of adopting a uniform system of terminology. The technicalities of science, often so ignorantly inveighed against, are in fact the instruments by which it effects its progress. New objects require new names, and new facts new phrases to express their relations; and the sooner the student can make himself familiar with those terms and their applications, the more rapid and pleasant will be his onward progress.

II.

GENERAL RELATIONS, STRUCTURE, AND CONDITIONS OF THE EARTH.

17. THE object and scope of Geology, it has been stated, is to investigate the history of our earth as revealed in the structure of the rocky or accessible crust. As this structure, however, is in a great measure dependent on certain general relations and conditions appertaining to the globe as a part of the solar system, it is as well to remind the student of this connection, and so place before him at the outset the entire data on which his own special science is founded. We shall therefore, in this chapter, advert to those general relations of motion, atmosphere, form, bulk, density, temperature, surface configuration, distribution of land and water, and constitution of ocean, which must always have influenced, and will ever continue to control and modify, all geological operations.

Planetary Relations.

18. The origin of all geological history is change; the cause of all change is motion; and the primary motions of the earth are those dependent on its relations to the solar system. From the sun the earth derives its light, heat, and it may be other more subtle influences (actinism, magnetism, &c.) which are indispensable to the growth and development of vegetable and animal life. Light and heat are modified in their distribution by the daily rotation of the earth on its own axis, by its annual revolution round the sun in an elliptical orbit, and also by the slanting position in which it revolves in that orbit. From these motions, and this peculiar position of the earth, arise the alternations of summer and winter in certain latitudes, of dry and wet seasons in others, and also that alternate impetus and retardation

which is given to the growth and reproduction of vegetable and animal life. To these seasonal differences belong, in like manner, those meteorological vicissitudes from drought to rain, from heat to frost, and from calm to storm, which produce so many geological changes on the rock-surfaces of the globe. On the earth's relation to the sun and moon—in other words, on the attractive force exerted by these bodies, depend also the bi-diurnal flow and ebb of the tides, which, as will afterwards be seen, are among the most permanent and important of geological agents.

19. It must be evident, therefore, from what we have thus briefly indicated, that any change in the planetary relations of the globe would be attended not only by a change in the distribution of light, heat, and meteorological influences, but also by a consequent alteration in the distribution and relationship of animal and vegetable life. As a necessary consequence also of any derangement of the existing planetary relations, there would be a change in the tidal influences, and a different distribution of sea and land. As at present the polar, temperate, and tropical zones of the earth are all marked by striking differences, not only in their botanical and zoological aspects, but in the degree and manner in which their rock-materials are wasted, shifted, and re-distributed; so would any alteration in the existing planetary relations of the globe be attended by new and different phenomena. The student is thus apprised of these great cosmical considerations that he may learn to familiarise himself with their mutual actions and reactions, and so be prepared to appreciate aright such hypotheses as alteration of the earth's axis of rotation, greater eccentricity of the earth's annual orbit, &c., which are sometimes advanced to account for geological phenomena.

[Although the chief planetary relations of the Earth seem fixed and immutable, there are certain minor phenomena which are now known to obey *laws of secular succession*, and this fact renders it possible that other phenomena, seemingly unchangeable, may be dependent on similar laws—the periods of recurrence being so vast that the variation within the limits of human history has as yet been unappreciable, or at all events has hitherto escaped scientific detection. Thus the magnetic needle which in 1660 pointed due north in London, began in 1662 to diverge to the westward, till in 1815 (a lapse of 155 years) it pointed 24½° west of north. Since 1815 it has been gradually returning from the extreme divergence, and we therefore regard it as obeying some law of secular succession. So also with the polar direction of the earth's axis, which we generally regard as pointing to one spot or "fixed point" in the heavens—namely, the polar star. This, however, is not strictly correct. The pole moves very slowly, so as to describe very nearly what is called *a small circle* in the heavens. This small circle, and the motion of the pole along it, are such that in 12,000 or 13,000 years the pole will be distant from the present pole by more than 40 degrees; but in some 25,000 years it will have returned

to the point in the heavens which it now occupies. As with these, which unrecorded observation could never have detected, so it may be with other phenomena which we now regard as fixed and immutable.]

Atmospheric Relations.

20. Another important consideration connected with the general constitution of the globe is its atmosphere or gaseous envelope, which surrounds it on every side, and is either of itself the cause of numerous terrestrial changes, or the medium through which they are effected. This atmosphere or air is essentially composed of nitrogen and oxygen gases—79 parts of the former to 21 of the latter—with a small percentage of carbonic acid and other extraneous impurities. As at present constituted, the air is indispensable to animal and vegetable life, and any alteration in this respect, however slight, would change the whole aspect of the vital economy. About *four* parts of nitrogen to *one* of oxygen forms, as we every moment experience, a breathable salubrious air; the same gases in different proportions produce a compound (nitric acid or aquafortis) so corrosive that even the metals are dissolved by it. Carbonic acid is exhaled by animals, but inhaled and assimilated by plants; any increase, therefore, in the percentage of this gas on the atmosphere, while it might add to the luxuriance of vegetation, would be poison and death to animals. Being an elastic or compressible medium, the air nearest the sea-level is denser than that at considerable elevations; and by calculating the rate at which this rarity takes place, it is estimated that at the height of 45 miles above the sea the atmosphere becomes so rare or light as to be inappreciable. The *absolute* height, however, as deduced from observations or polarisation made at the tropics by M. Liais in 1858, is stated to be 211, or in round numbers, 210 miles.

21. We have thus surrounding the globe a gaseous envelope 210 miles in absolute thickness, having a certain ascertainable density at the level of the sea (its pressure being estimated at 14½ lb. avoirdupois on the square inch), and gradually becoming rarer or more attenuated as we ascend to its extreme upper limit. Through it the heat and light of the sun are equally diffused and modified; and it is also the great recipient and diffuser of all watery vapours arising from the earth. Local alterations in its density or expansibility caused by heat and the like, produce aërial currents—some of them regular and steady, like the trade-winds—others violent and fitful, as whirlwinds and hurricanes. The atmosphere, in fine, is the great laboratory in which

all meteorological and electrical phenomena are elaborated; hence all the varied aspects and results of winds, clouds, rains, snow, hail, and thunderstorms. These and kindred phenomena, as will afterwards be seen, are continually operating on the earth's surface—mechanically as rains and winds; chemically as carbonic acid and oxygen; electrically as thunderstorms; and vitally as in the support of plants and animals.

["It has hitherto been considered," says Sir John Ross, in his *Antarctic Voyages*, "that the mean pressure of the atmosphere at the level of the sea was nearly the same in all parts of the world, as no material difference occurs between the equator and the highest *northern* latitudes—the mean being about 29°.85. In the *southern* hemisphere, however, our barometrical experiments appear to prove that the atmospheric pressure is considerably less at the equator than near the tropics; and to the south of the tropic of Capricorn, where it is greatest, a gradual diminution occurs as the latitude is increased—the mean at the equator being 29°.974, at the tropics 30°.085, and at lat. 74° S. only 28°.928."]

Figure of the Earth.

22. The earth, as revolving in space and surrounded by its atmospheric envelope, is of a globular or spherical form. The limits of this form have been defined by astronomers with admirable precision; but it is enough for our present purpose to state the result in approximate numbers. Measured from north to south—that is, from pole to pole—the diameter of the earth is 7899.170 miles; while measured from east to west, through the equator, the diameter is 7925.648 miles. The equatorial diameter thus exceeds the polar by somewhat less than 26½ miles, thereby producing a deviation from the true globular form; in other words, the earth is an oblate ellipsoid of revolution, flattened at either pole, and bulging out at the equator to the extent above mentioned. Such a figure arises from the rapid rotation of a globular mass of yielding material on its own axis, and is due to what is termed "centrifugal force;" and such is presumed to be the cause of the earth's spheroidal form.

23. We have no certain evidence, geologically speaking, of the earth ever having been in a molten or semi-fluid condition; but it is important as bearing on geological speculations to know that its figure is such as would arise from the rotation of a soft or yielding mass round its own axis. The earth's mass, as is well known, is kept together by the force of *gravitation;* and had it remained at rest, its form would have been perfectly spherical; but the moment it began to turn on its own axis, the particles of

its mass began to obey another law—viz., that of *centrifugal force*, which exerts itself at right angles to the axis of rotation, and in proportion to the distance from that axis. Hence the greater bulging out of the earth's mass at the equator, where the distance from the axis is greatest; and hence also the gradual declension of centrifugal force as we proceed towards the poles. Gravitation and centrifugal force are thus opposable or counteracting powers; and any variation in the earth's size through expansion by heat or contraction by cooling, any variation in density or in velocity of rotation, would be attended by a proportional deviation from the true form of a sphere. Geology, in attempting to account for axes of elevation and depression, for lines of fracture and other kindred phenomena in the earth's crust, may guess at conditions of original igneous fluidity or aqueous plasticity in the mass, and may hint at some great law of secular contraction; but it must be confessed that on these and similar points science is yet unable to offer anything like the certainty of demonstration.

Density of the Globe.

24. The density of the globe, as compared with the materials known in and upon its crust, has been ascertained with considerable precision. The average or mean density of the most prevalent rocky substances is about 2½ times that of water; the density of the whole globe, as ascertained by astronomical experiments, is about 5½ times that of water—that is, distilled water, at the temperature of 60° Fahrenheit. From experiments with the torsion-rod, Cavendish gives it as 5.48; M. Reich as 5.44; and, more recently, M. Bailly as 5.6746; while the Ordnance surveyors, under Colonel Sir Henry James, make it 5.316, as obtained from the attraction of Arthur's Seat, near Edinburgh. As a whole, therefore, the globe is of greater density than the rock-materials which form its crust, and consequently cannot be composed throughout of these materials. Besides, were it composed of such materials, and the law of gravitation acting uniformly towards the centre, a depth would soon be arrived at where the density of ordinary rocks would become so great, as to give a mean density to the earth greater than that which its astronomical relations will allow. It has been calculated, for instance, that air, at the depth of 84 miles from the surface, would become as heavy as water; that water, at the depth of 362 miles, would be as dense as quicksilver; and that the density of marble, at the centre of the earth, would be 119 times greater

than what it is at the surface. All this leads to the supposition that the earth, in its interior parts, is composed of substances differing in constitution from those that form its crust; hence, to reconcile its mean density ($5\frac{1}{2}$ times that of water) with the forces of attraction and gravitation, it has been suggested that the central portions may consist of matter as attenuated as the lightest known gases, or even as subtle as light itself. Such conjectures, however, are beyond the pale of geological deduction, which limits itself to the accessible crust—to that which can be seen, handled, and examined.

25. Our knowledge of the earth as a solid mass, in as far as it bears on geological speculations, may be briefly stated:—1st, The density of the crust is about $2\frac{1}{2}$ times that of water; 2d, The mean density of the whole mass is $5\frac{1}{2}$ times that of water; 3d, The central parts cannot consist of such substances as are found in the crust, otherwise their compression towards the centre would produce a much greater mean density than five times that of water; 4th, The condensation of the central mass must be counteracted by some expansive influence, such as heat, or its nature must be altogether different from any substance with which we are acquainted; and, 5th, The ponderable crust, calculating from the astronomical phenomena of precession and nutation, cannot be less than a fourth or fifth of the earth's radius—that is, cannot be much less than 800 miles.

Temperature of the Earth.

26. Closely connected with the density of the globe is its temperature, or the amount of heat that pervades it. As one of the orbs of the solar system, the earth has a variable and irregular surface temperature; it has also a temperature peculiar to the rocky crust; and, judging from volcanic action, there is also a higher and more remarkable interior or central temperature. Respecting the *surface temperature*, it may be stated, that it is influenced from day to day, and from season to season, by the heat of the sun; that it varies according to the latitude, being greatest at the equator, and gradually decreasing towards the poles; that it is greatly modified by the extent and distribution of sea and land—the sea and sea-coasts being more equable than inland continents, which experience extremes of heat in summer, and extremes of cold during winter; that it is also modified by the absorbent or radiating nature of the soil, according as this is dark or light coloured, dry or moist, porous or compact; and,

lastly, that it is notably affected by elevation above the mean level of the sea—the higher being the colder regions. The surface temperature of the globe—that is, the laying down of lines of equal heat (isothermal, isocheimal, and other lines)—belongs more especially to physical geography ; still, so much relating to the distribution of plants and animals—the waste of continents and transport of rock-materials—depends on a knowledge of its leading facts, that the geological student cannot be too early reminded of its connections and importance.

27. The *temperature of the accessible crust* is affected either by the direct heat of the sun, by heat radiated from the moon, by heat generated chemically among its own materials, or by heat derived by conduction from the interior. During summer, for instance, the earth is warmed to a certain depth by the heat of the sun ; during winter, the heat is again given off to the surrounding atmosphere ; and though the heat of one summer and the cold of one winter may differ from the heat and cold of others, still, on an average of seasons, the results are pretty equable. It may, therefore, be laid down as an axiom, that in summer the crust of the earth at small depths is colder than at the surface ; and that, during winter, the crust at these depths is warmer than at the surface, which is more immediately exposed to the passing cold. As to the heat generated within the crust by chemical action we have no accurate knowledge, though it appears certain that magnetic and electric currents, as well as the molecular changes incessantly taking place within rock-masses, could not possibly occur without the evolution and dispersion of heat.

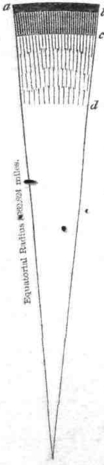
[By many experiments in Scotland, France, Belgium, and Germany, which have been carefully collated by Leslie, Quetelet, Forbes, &c., it is found that the middle of summer and winter, so to speak, occur—

At the surface, in July and January ;
3 feet deep, in August and February ;
12 feet deep, in October and April ;
24 feet deep, in December and June ;
And at less than 100 feet (say 90 feet), the variations of summer and winter become wholly insensible.]

[Professor Piazzi Smith's astronomical stations on Teneriffe, in 1856, were at the altitudes 8840 ft. and 10,700 ft. respectively ; and even at the lowest station the heat radiated from the moon was distinctly perceptible. How much greater this heat may have been during the earlier ages of our lunar satellite, and how much the climate of the earth may have been affected thereby, are questions now fairly opened to those who delight to indulge in geological speculation.]

28. Respecting *the heat of the interior*, we see it abundantly manifested in hot springs, volcanoes, and the like ; and have, by direct experiment, been enabled to arrive at some important facts

relative to its descending rate of increase. Thus, it has been ascertained that, at a certain depth in the crust of the earth, the temperature remains stationary, and uninfluenced by summer's heat or winter's cold; and this depth may be reckoned at from 60 to 90 feet, according as the material passed through is solid rock, clay, sand, or water. Below this depth, which has been called "the stratum of invariable temperature," it has been found, by experiments in coal-pits, in artesian wells, and in metalliferous mines, that a rise of one degree of Fahrenheit's thermometer takes place for every 55 or 60 feet of descent; and calculating at this rate of increase, a temperature (2400° Fahr.) would be reached at a depth of 25 miles or thereby, sufficient to keep in fusion such rocks as basalt, greenstone, and porphyry. At the same rate of increase, or even admitting, as some contend, that the thermometer only rises one degree for every 90 feet, we would, at the depth of 150 miles or thereby, arrive at such a temperature (100° Wedgewood's pyrometer) that the most refractory rock-substances would be dispersed before it like vapour. We know little, however, of the deportment of heat under such a pressure as must exist at these depths, and can only indicate the line of reasoning which leads to the general geological belief that the solid or rocky crust forms but a comparatively thin film or rind, and that the great interior mass exists in a state of high incandescence or molten fluidity.



29. In a previous paragraph it was seen, that astronomical calculation set down the appreciable or ponderable crust at a thickness of 800 miles; the probability has also been shown, that not more than 150 miles of the exterior of this can be in the condition of molten rock-matter; while at a depth of 25 miles or thereby there exists a temperature sufficient to keep in fusion a large proportion of the rocks with which we are acquainted at the surface. Throwing these results into the form of an approximate diagram, we shall have the dotted line *a* indicating the stratum of invariable temperature; *b* the limit of the solid rock-crust; *c* that of the molten zone; and *d* that of the appreciable or ponderable portion which envelopes the unknown interior. Looking at the comparative

thinness of the solid crust, one can readily conceive how much it must be affected by any commotion in the interior zones, or by any contraction or expansion of the entire mass. Hence the tremors, the undulations, the upheavals and subsidences occasioned by earthquake and volcanic convulsions; and hence also the fissures and fractures which everywhere traverse the rocky crust, whether they may have arisen from the efforts of local forces, or from the operations of some unknown but general law of secular contraction.

30. Whatever be the exact proportions and conditions of the crust and interior of the earth, we know enough of its temperature to warrant the following general conclusions:— 1. That the surface temperature is mainly derived from the sun, and that though variable and irregular during any one season, it is, on an average of many seasons, capable of being laid down with considerable certainty; 2. That the temperature of the crust, as depending on external heat, is also variable to the depth of from 60 to 90 feet, but that at this limit it remains stationary; 3. That downwards from this invariable stratum the temperature increases at the rate of one degree for every 55 or 60 feet, and that at this rate a temperature would soon be reached sufficient to keep in fusion the most refractory rock-substances; 4. That this high internal temperature is apparently the cause of hot springs, volcanoes, earthquakes, and other igneous phenomena, which make themselves known at the surface; and, lastly, That intense as the interior heat may be, the surface of the globe is scarcely, if at all, affected by it (according to Fourier, only 1/17th of a degree), owing to the weak conducting properties of the rocky crust.

Surface Configuration.

31. Although it is properly the province of geography to describe the surface aspects of the globe, these aspects are produced by the operations of geological agents, and again react in producing new geological phenomena. On the whole, the surface configuration of the globe is extremely irregular—here spreading out in vast plains and plateaux, there rising up in abrupt mountain-chains, here undulating in gentle hills and valleys, there sinking in deep ravines or shooting up in craggy precipices; here stretching out in fertile alluvial fields, and there in expanses of barren desert sand. Still, though presenting all this irregularity, it is possible, by tracing the direction of mountain-chains and

valleys, to establish certain systems or plans of arrangement; and by such arrangements to arrive at important conclusions respecting temperature, fall of rain, drainage, distribution and growth of plants and animals—in fine, at conclusions intimately connected with the causes now productive of geological change on the face of the globe. Thus, without a knowledge of the surface configuration of a country, the altitude and steepness of its hills, the breadth or abruptness of its valleys, and so forth, it would be impossible to arrive at any conclusion respecting the waste caused by streams and rivers, the effects of frosts, snows, and glaciers, the phenomena of periodic rains and inundations, the limits and exuberance of vegetable growth, and the distribution and dispersion of animals.

32. Elevation above the level of the sea is, perhaps, one of the most striking and appreciable of superficial phenomena. As we ascend above the sea-level, the temperature sinks at the rate of one degree Fahrenheit for every 350 feet of elevation; and as the sea-level temperature varies according as the latitude is tropical, temperate, or arctic, so we attain the height at which snow perpetually lies much sooner in temperate than in tropical regions. Thus in Iceland, and at the North Cape (lat. 71° 10′), the snow-level is about 2000 feet above the sea; in Norway it ranges from 4000 to 6000 feet; on the Alps and Pyrenees from 8000 to 9000; while under the tropics the same altitudes are clothed with the verdure of luxurious forests—the snow-line not being reached till we attain the height of 16,000 and 18,000 feet in the Peruvian Andes and Southern Himalayas. It is for this reason that, in ascending a mountain from the sea-level to the limit of perpetual snow, "we pass," says Herschel, "through the same series of climates, so far as temperature is concerned, which we should do by travelling from the same station to the polar regions of the globe; and in a country where very great differences of level exist, we find every variety of climate arranged in zones according to the altitude, and characterised by the vegetable productions appropriated to their habitual temperatures." And so it happens, that under the tropics an elevation of a few thousand feet produces a climate and vegetation akin to that of temperate latitudes; while at the base of these heights the valley may be teeming with the rankest growth of a tropical flora. A snow-clad mountain-range crossing a continent forms a more impassable barrier to the migration of plants and animals than even the ocean itself; while its crags and ravines, under the influence of frost and snow, avalanches and glaciers, exhibit an amount of geological waste, and give

birth to a series of rivers of a totally different character from those which characterise lower and flatter regions under the same parallels of latitude. Nor is it alone the temperature that decreases with altitude, there is also greater dryness (in virtue of the general law of atmospheric rarity) in its higher strata; and thus we have moisture, amount of cloud, force and direction of winds, all less or more altered from their normal condition at the sea-level in the same latitudes. A country, also, whose valleys discharge themselves at right angles to the coast-line, and are thus exposed to the influence of the sea-breeze, exhibits phenomena of climate and vegetation very different from those exhibited in a country whose main valleys run parallel to the coast-line, and are consequently shut out from the ocean. These, and other conditions which must at once suggest themselves to the reflecting student, are so numerous and varied, that we can thus only indicate their nature, and the results to which they give origin.

[Several of the effects of extreme altitude have been well illustrated by Professor Piazzi Smith during his recent sojourn on the heights of Teneriffe. Thus, on the peak (12,205 feet), the summer wind is habitually S.W., and the sky almost always cloudless, while at the foot of the mountain the N.E. trade prevails, and a dense stratum of cloud covers the surrounding ocean. Not only the *amount* but the *quality* of solar radiation is affected, and, by the greater absorption of the actinic rays, the colouring of the flowers is more brilliant in the higher than in the lower regions. Again, owing to the dessication of the higher aërial strata, nothing save *lichens* were found from the peak downwards to 10,000 feet; from 9800 feet to 5700 feet the *Cytisus nubigensis* formed an exclusive zone of vegetation; next the *Erica arboracea* prevailed from 5700 to 3000 feet; and from 3000 feet downwards there occurred a mixed zone, in which ferns gave place to the laurel, the laurel to the vine, and so on to the sea level—3000 feet being the lower level of the perennial mountain-cloud which separates the upper from the lower wind-currents.—It has often been surmised, and even asserted, by some of our highest authorities, that the diminished atmospheric pressure which takes place at great elevations may have some direct effect in producing an alpine character on the vegetation. On this subject Dr Hooker, in his *Himalayan Journals*, very decidedly remarks: "I know of no foundation for this hypothesis; many plants, natives of the level of the sea in other parts of the world, and some even of the hot plains of Bengal, ascend to 12,000 and even 15,000 feet in the Himalayas, unaffected by the diminished pressure. It is the same with the lower animals; innumerable instances may with ease be adduced of pressure alone inducing no appreciable change, whilst there is absence of proof to the contrary. The phenomena that accompany diminished pressure are the real causes of change and specific peculiarity—of which *cold* and the *excessive climate* are perhaps the most formidable."]

Distribution of Land and Water.

33. Intimately connected with the surface configuration of the globe—forming, indeed, one of its prominent superficial aspects—is the distribution of land and water. At present about three-fourths of the earth's superficies is covered by water; that is, if we assign 51 millions of square miles to the land, there will remain about 146 millions for the extent of surface covered by the ocean—this ocean surrounding or insinuating itself into the recesses of the land in a very irregular manner. The dry land appears in the form of continents and islands; the water spreads out into oceans, seas, bays, and gulfs. The land rises variously and irregularly above the level of the water, generally at some considerable altitude—occasionally, as in the Andes and Himalayan ranges, to 27,000 and 28,000 feet. The depth of the sea also varies from low shallow shores and shoals only a few fathoms under water, to depths beyond the reach of the sounding-line, which has been sunk to full 27,000 feet in the South Atlantic. This relative depth of sea and altitude of land forms an important cosmical consideration, as on it depend many of the conditions that regulate the kind and distribution of vegetable and animal life. Thus, as the waters only occupy those portions of the earth's surface depressed below a certain level, it is evident that the wider these areas of depression the shallower the seas, and the greater their proportion to the dry land. A wider area of sea and a less elevated surface of continent and islands would materially modify the temperature of the globe—would give rise to a milder and more equable climate, and to a more general diffusion of the same aspects of vegetable and animal existence. On the other hand, more elevated continents, and deeper and more contracted seas, would be attended with a diminution of general temperature, and a breaking up of vegetable and animal forms into numerous local and limited aspects. At present the greater proportion of dry land exists in the northern hemisphere; and were this land elevated a few thousand feet, a great portion of it would then be reduced to boreal conditions, while much of it would be placed altogether beyond the limits of organic endurance. The student will thus perceive how important the results depending on the relative height of land and depth of ocean; and will be prepared to admit how greatly the former conditions of the globe may have been influenced by this single relation.

34. Nor does the relative configuration of sea and land exert

a less general or important influence. At present a certain mean annual temperature is found to prevail over certain latitudes, and this temperature or climate we know depends in a great measure upon the configuration of the existing continents. Had these continents, therefore, been less broken up by seas, had they lain in solid masses, or had they lain in an east and west direction, instead of stretching southward in long spur-like projections, there cannot be a doubt that their climates would have been much more rigorous and severe. On the other hand, had they been more broken up by inland seas, their mean temperature would have been increased; and with this exalted temperature and a greater area of shallow sea exposed to evaporation, there would have been more genial climates, greater atmospheric moisture, and a more luxuriant growth of sub-tropical vegetation. Nor is it alone on the vital conditions of the globe that this configuration exerts its influence; it also exercises direct and important geological influences of a more mechanical nature, by determining the direction of tidal and oceanic currents, and by modifying the height and force of waves. As will afterwards be seen (CHAP. III.), tides and waves are most important agents of geological change—here wasting and degrading, there transporting and piling up the waste material, and in these ceaseless operations retarded or augmented by the configuration of the coast-line—its headlands, promontories, and bays. The tide, that travels at the rate of six or eight miles an hour in the German Ocean, and rises from 12 to 20 feet, creeps almost imperceptibly along the shores of the land-locked Baltic, where its rise is scarcely as many inches. The tidal phenomena of the Bay of Biscay, or the Bristol Channel, with a rise of from 30 to 40 feet, must be altogether different from those of the Mediterranean, where the pulsation is scarcely felt; and the geological results arising from the ordinary tide which flows along the open coast of North America, can scarcely be compared with those depending on the gigantic surge that rushes to the height of 60 or 70 feet into the *cul de sac* of the Bay of Fundy. All these, and similar differences connected with tidal action, are thus directly attributable to the relative configuration of sea and land. So in like manner with the height and force of the waves; and so also with oceanic currents like the "Gulf Stream," which are not only the transporters of products from one region to another, but the equalisers of temperature and warmth among the waters of the ocean, and the modifiers of the distribution of marine life, as well as of the life of the seaboards against which the flow of their waters impinges.

Constitution of the Ocean.

35. Respecting the constitution of the ocean—that is, the composition of its water, its temperature, pressure, and so forth—observation and analysis supply the geologist with many important facts. Unless along coasts subject to abrasion by waves and tides, at the mouths of rivers, and in the course of great sea-currents, there is very little matter *mechanically suspended* in the waters of the ocean. After storms and land-floods the sea in some regions is turbid for many leagues off shore; but when the storm and floods have subsided, the water soon regains its transparency, except in such areas as the Yellow Sea, the Bay of Bengal, the estuary of the Amazon, &c., where the river-borne debris renders it always less or more muddy and discoloured. The substances held in *chemical solution* are chloride of sodium (common salt), chlorides and sulphates of magnesia and lime, together with minor and varying proportions of salts of potash and ammonia, iodides and bromides of sodium, carbonate of lime, silica, &c., amounting in all from 3½ to 4½ grains in the hundred of water; or giving sea-water, as compared with absolutely pure water at 62° Fahr., a mean specific gravity of 1.0275. These ingredients vary in different seas, but only to the extent of a fractional percentage. Thus it is said that the waters of the Southern Ocean are salter than those of the Northern; that the greatest saltness takes place between 22° north and 17° south of the equator; that from these limits towards either pole there is a slight progressive diminution; that inland seas, like the Baltic and Mediterranean, though communicating with the ocean, are less salt than the ocean; and though the saltness of the sea be pretty uniform at great depths, still at the surface, owing to the admixture of rain, river-water, iceberg water, &c., it is not quite so salt. It has also been ascertained that the water from the surface contains less air than does that from depths, and the difference may equal one-hundredth of the volume of water. These and similar facts serve to explain certain phenomena connected with oceanic life, as it is from these saline ingredients that shell-fish, corals, zoophytes, and sea-plants derive the solid matter of their structures, and as it is also owing to this composition of the ocean that marine plants and animals assume different aspects from those of the land and fresh waters.

36. Respecting the temperature of the ocean, few reliable or sufficiently extended observations have yet been made. We know, however, that it is more equable than that of the land; and that,

though the superficial portions are colder in summer than the surrounding atmosphere of any contiguous district, they are in winter always several degrees higher—thus exercising the function of a great storehouse of heat for modifying and equalising the climates of the adjacent lands. The surface temperature is necessarily highest at the equator, and gradually diminishes as we approach either pole. At the depth of about 60 fathoms the temperature is pretty constant under every latitude, but gradually sinks as we descend, till the enormous depth of 2000 fathoms is reached, and then it seems to remain stationary at the *minimum* of 35°. Its *mean temperature*, from such experiments as have been made, is estimated at 39½°, or 7½° above the freezing-point of pure water, and as nearly as possible at the point of its mean density. Salt water is also less sensitive, if we may so speak, to cold than fresh water—the latter freezing, as is well known, at 32°, while sea-water is not converted into ice till the thermometer sinks to 28¼° Fahrenheit. It is also less vaporisable than fresh water—that is, a given extent of salt-water surface gives off less vapour during the same time and under the same conditions than an equal extent of fresh-water surface.

[According to the experiments of Sir John Ross (*Voyage to the Southern Seas*, vol. ii. p. 377), the circle of mean temperature of the ocean in the southern hemisphere lies between the 56th and the 57th parallels of latitude—along which belt the uniform temperature of 39½° has been found to prevail at all depths, from the surface downwards. To the south of this line, owing to the absence of solar heat, the surface-depths are colder, and the mean of 39½° is not reached in the 70th parallel till we descend to the depth of 750 fathoms, beneath which, to the greatest depths, the temperature is uniformly at 39½°, while the surface temperature is only 30°. To the north of the line of mean temperature, in consequence of the absorption of the sun's heat, the surface-depths are warmer; and in the 45th parallel the mean temperature of 39½° is not reached till we descend to 600 fathoms; while at the equator we have to descend 1200 fathoms before the same mean is obtained, and then at all depths below this it maintains the unvarying mean temperature of 39½°, though the surface is at 78°! "These observations force upon us," continues Sir John, "the conclusion that the internal heat of the earth exercises no influence upon the temperature of the ocean, or we should not find any part in which it was equable from the surface to the great depths we have reached—a new and important fact in the physics of our globe."]

37. Again, water being slightly compressible, it follows that at great depths in the ocean the water will be denser than at the surface, and consequently what takes place near the shores will be impossible at extreme depths. According to experiment, water at the depth of 1000 feet is compressed $\frac{1}{340}$th of its own bulk, and under this rate of compression we know that at great depths animal and vegetable life as known to us cannot possibly

exist—the extreme depressions of seas being thus, like the extreme elevations of the land, barren and lifeless solitudes. Further, at great depths, sand, mud, and all loose debris, will be compressed and consolidated; and, according to the experiments of Sir James Hall, even limestone could be fused without the loss of its carbonic acid under pressure of a column of water 1708 feet in height. The effect of depth in regulating the distribution of species is one of the prettiest problems in zoology, every zone from the shore seawards being characterised by different specific forms; and, as will hereafter be seen (par. 68), the comparative depths of seas of deposit may be ascertained with considerable certainty by a study of the fossils found in such deposits.

[Since the experiments of Sir J. Hall, it has been discovered that pressure has less to do with the retention of carbonic acid gas than the nature of the circumjacent atmosphere; hence, as is stated to be the case by Professor Faraday, masses of limestone are sometimes fused and crystallised even in common lime-kilns. Carbonate of lime can be heated to almost any degree, according to Faraday, in an atmosphere of carbonic acid gas, without being decomposed; and Gay Lussac found that fragments of limestone, placed in a tube and heated to a degree not sufficient by itself to cause their decomposition, yet immediately evolved their carbonic acid when a stream of common air or steam was passed over them. Gay Lussac attributes this to the mechanical displacement of the nascent carbonic acid gas. Referring to these facts, Mr Darwin remarks that he has seen limestone crystallised by the heat of superincumbent lava, where the flow must have taken place in comparatively shallow water, and where the retention of the carbonic acid gas could only be accounted for on the principles discovered by Faraday and Lussac.]

NOTE, RECAPITULATORY AND EXPLANATORY.

38. In the preceding chapter we have endeavoured to present an outline of those general conditions and relations which belong to the earth as a planet, and which lie at the bottom of all the physical changes its surface has undergone. The minuter details of these relations belong to Astronomy and Physical Geography; but enough, we presume, has been stated to convince the geological student of the importance of such considerations, and to put him on the way of working out for himself the higher problems they involve. So long as the Earth is subject to the laws of the planetary system of which it forms a part, so long will the general conditions concomitant with these laws continue to impart a steadiness and uniformity to the geological operations that take place on its surface. No doubt, the forces of gravitation and

heat cannot be exerted without producing motion, and motion implies change of place or change of condition; but such changes may either constitute a limited and recurring *succession*, or form part of an unlimited *progression*, of which we see only a passing portion, and from that portion can infer something of what has gone before, and something of what is yet to follow. It is on a belief in this steadiness and uniformity in the operations of nature that we build all our knowledge; and, so far as science can discern, nothing has occurred during the few thousand years of man's experience to invalidate the conviction. Whether, therefore, the changes our earth has undergone be part of a recurring succession of such modifications, or belong to a vast cosmical progression, we are bound alike by science and reason to account for them on the principle of natural law, and to reject every suggestion, however ingenious, which ignores this foundation. When such hypotheses, then, as nebular condensation, original igneous fluidity, change of axis of rotation, secular contraction of the earth's mass, highly carbonated atmosphere, the passage of the solar system through colder and warmer regions of space, and the like, are advanced to account for geological phenomena, the student must receive them merely as *hypotheses*, not as the "*true and sufficient causes*" of inductive philosophy. The legitimate progress of human science lies over a pathway of observation, fact, and deduction, and is little aided by conjecture, however plausible and possible. If, in any instance, we cannot account for geological phenomena by the existing conditions of our planet, and the complex operations to which their mutual relations may give rise, let us rather rest contented with a simple description of appearances, than appeal to causes the existence of which science is not yet prepared to substantiate. Let us strive first to exhaust the range of normal causation in existing nature, and even then let us continue to work and watch, rather than fall back on the idle and unphilosophical resort of abnormal conditions in primeval nature.

39. In speaking of the General Relations and Conditions of the Globe—its motions, figure, density, atmosphere, temperature, surface configuration, and so forth—our object was to indicate their bearings on geological problems, not to enter upon a full statement of facts and numerical details. The student who feels inclined to go more fully into such particulars, and to know something of the processes by which philosophers have arrived at the facts to which we have alluded, will find ample information in Herschel's *Elements of Astronomy* as to the planetary relations of the earth; in the article "Physical Geography," by the same

author, in the *Encyclopædia Britannica* (since published in a separate form), as well as in the latest edition of Mrs Somerville's *Physical Geography*, all that appertains to the distribution of land and water, surface configuration, and external temperature; in A. K. Johnston's *Physical Atlas* he will find these peculiarities depicted in a manner still more accessible and comprehensive; in Bischoff's *Physical Researches* and Buff's *Physics of the Earth* he will obtain much valuable information relative to internal temperature; in Maury's *Physical Geography of the Sea* he will find all that is yet known with certainty respecting the constitution of the ocean; while in Guyot's *Earth and Man* he will meet with an eloquent generalisation of the physical conditions as they bear on the higher problems of vital economy.

III.

GEOLOGICAL AGENCIES RESULTING FROM THE GENERAL RELATIONS OF THE EARTH; OR THOSE CHIEFLY CONCERNED IN THE MODIFICATION OF ITS ROCKY CRUST.

40. THE aim of geology being to furnish a history of the structure and past conditions of the globe, it is evident there can be no accurate conception of this structure without a knowledge of the causes which have chiefly operated in its production. Before we can decipher, for instance, the geological structure of any locality on which we may be situated,—that is, before we can tell whether its rocks are the growth of some peaty morass or the silt of some fresh-water lake—the sandy accumulations of some ancient sea-shore or the delta of an estuary—the heterogeneous deposit of a former sea-bottom or the cooled and consolidated products of volcanic eruption,—we must in some measure make ourselves acquainted with the mode of vegetable growth and decay, the operations of wind and water, the action of tides and waves and currents, the difference between fresh and salt water accumulations, the modes of aqueous deposition and of igneous fusion, and generally with the principal agents productive of geological change. In fact, we must learn to reason from the known to the unknown; and from the obscurer appearances in the rocky crust, appeal to the phenomena that are now taking place beneath and around us—ever bearing in mind the differences that would arise from any modification of the great cosmical relations adverted to in the preceding chapter.

41. Had the exterior crust been subject to no modifying causes, the world would have presented the same appearance now as at the time of its creation. The distribution of sea and land would have remained the same; there would have been the same surface-arrangement of hill and valley and plain; and the same unvarying aspects of vegetable and animal existence. Under such circumstances, geology, instead of striving to present a consecutive

history of change and progress, would have been limited to a mere description of permanently enduring appearances. The case, however, is widely different; from the moment the earth began to revolve round the sun, there has been one continuous series of change and progression. Alternations of heat and cold; winds, frosts, and rains; springs, streams, and rivers; tides, waves, and currents; the shivering of the earthquake, and the upheaving of the volcano; the alternate growth and decay of plants and animals; and the universal operations of chemical and electrical agency, are all continually tending to separate, to combine, and re-arrange the materials composing the crust of the earth. There may be periods of comparative rest and quiescence, but none of stagnation or stability. The operations of nature are incessant; and their results constitute one great chain of sequence, from the dawn of creation up to the present hour, which is in like manner pressing on into the hours and years that are to follow.

42. In a comparatively fixed and stable region like our own, one is apt to underrate these results and the causes that produce them. We see from our infancy the same hills and valleys, the same fields and woods and streams, and are apt to infer that little or no change is going forward. As we note more attentively, however, we begin to perceive that changes have taken place—are yearly, daily, and hourly taking place around us. We see the river deepening its channel, the tides and waves wearing away the sea-cliffs, the frosts and rains crumbling down the rocky surface, the estuary filling up with sandbanks, and the lake in which we laved our young limbs becoming shallower, and a large portion of it transformed into a marsh, luxuriant with reeds and rushes. If all this has taken place during some twenty or thirty years, what, we naturally ask, may have taken place during centuries?—and what the amount of change, when centuries have been multiplied by centuries? Nay, more, if a few years can work such changes in a district of comparative rest and stability, what are we to expect over the whole surface of the globe, and especially in regions whose lakes are like our seas, and compared with whose rivers our streams are tiny threads of water—regions of extremes, where rains fall in torrents—where inundations deface, earthquakes submerge, and volcanoes elevate and give birth to new mountains? Extending his views in this manner, the attentive observer soon discovers that the crust of the earth, instead of being a thing of permanence and stability, is subject to incessant change; and as he carries his thoughts over the lapse of centuries, he can readily perceive how sea and land may have frequently changed places—how old mountain-ranges may have sunk, and

new ones been elevated—the beds of lakes become *alluvial* tracts (*ad*, to, and *luo*, I wash—formed by the operations of water), and the sands and muds of former shores been converted into solid strata.

43. The causes which produce these changes, being dependent on the original constitution of our planet, are of course everywhere present and in ceaseless operation — acting silently and imperceptibly in one region, and violently and on a gigantic scale in another; scarcely appreciable in their results at one period, and producing at another the most extensive alterations on the surface configuration of the earth. It is indispensable, then, that the student should have a thorough comprehension of their nature and mode of operation, and for this purpose they may be conveniently described under the following arrangement:—1. *Atmospheric*, or those operating through the medium of the atmosphere; 2. *Aqueous*, or those arising from the operations of water; 3. *Organic*, or those depending on vegetable and animal growth; 4. *Chemical*, or those resulting from the chemical action of substances on each other; and, 5. *Igneous*, or such as manifest themselves in connection with some deep-seated source of heat in the interior of the globe.

Atmospheric Agencies.

44. Of the agents operating on the crust of the globe, and tending to modify its structure and conditions, those connected with the atmosphere, though not the most powerful, are by far the most general in their diffusion. The atmosphere, as we have seen, envelops the earth on every side; acts mechanically by its currents of wind, chemically by the gases of which it is composed, and vitally in its being indispensable to vegetable and animal life. Thus, winds blow and drift about all loose material, carrying them away from one spot and piling them up in another. Such accumulations are termed *sub-aërial*, and by some *Eolian* (from *Eolus*, the god of wind), in contradistinction to those formed under water, and which are consequently reguarded as *aqueous* and *sub-aqueous*. The sandy tracts so frequent along our own shores, as well as along the shores of almost every country, and known as *sand-drift* and *sand-dunes* (*dune* being the Saxon word for a mound or hillock), are the results of wind-drift—the wind carrying the dry sand left by the tides forward and landward beyond the reach of the waters. All expanses of shifting sand, whether maritime, or inland like the deserts of Africa and Asia, are yearly

modified by the same agency; and where the aërial current blows steadily for some time in one direction, as the trade-winds and monsoons of the tropics, it will carry forward the drifting material in that direction. Hence the gradual entombment of fields, forests, and villages that lie in the course of such progressive sand-waves, as on the Biscay seaboard of France, and on the western verge of Egypt. Results like these arise from the ordinary operations of wind; its extraordinary operations are manifested in the hurricane, whirlwind, and tornado. In the preceding instances winds may be regarded as *directly* productive of geological change; while in the raising of waves and breakers they act indirectly in modifying the crust of the earth.

45. Frost, which may be regarded as another mechanical phase of atmospheric agency, is also, under certain latitudes, an important modifying cause. The rain and moisture that enter the fissures of cliffs, and between the particles of all rocky matter, are often frozen during winter, and in this state of ice expand and force apart these rocks and particles. When thaw comes, the particles, having lost their cohesion, fall asunder; and thus, under all latitudes, and at all altitudes where frost occurs, vast waste is every winter effected. The student may note the effects of frost on every ploughed field, and on every cliff and railway-cutting around him; how it breaks up and pulverises the soil, eats away the cliff, and leaves every winter at its base a sloping mass—in geological language, a *talus*—of crumbling debris.

["The influence of the cold," says Von Wrangell, speaking of the December temperature of Siberia, which was 58° below freezing, "extends even to inanimate nature. The thickest trunks of trees are rent asunder with a loud sound, which in those deserts fell on the ear like a signal-shot at sea; large masses of rock are torn from their ancient sites; the ground, in the tundras (mossy or boggy flats) and in the rocky valleys, cracks, and forms wide yawning fissures, from which the waters which were beneath the surface rise, giving off a cloud of vapour, and become immediately changed into ice." Again, "In the middle of winter the water sometimes suddenly disappears from the numerous shallow lakes of Northern Siberia, and this without any side-channels being visible. In such cases a loud noise is heard at the time the water disappears, and when the bottom of the lake is laid bare, large clefts are visible, occasioned by the severity of the frost." Similar phenomena are noticed by Sir John Ross in his *Antarctic Voyages*; and Dr Hooker, in his *Himalayan Journals*, while at an elevation of 16,000 feet, says—"The descent was to a broad open valley, into which the flank of Nango dipped in tremendous precipices, which reared their heads in splintered snowy peaks. At their bases were shoots of debris fully 700 feet high, sloping at a steep angle. Enormous masses of rock, detached by the action of the frost and ice from the crags, were scattered over the bottom of the valley; they had been precipitated from above, and, gaining impetus in their descent, had been hurled to almost inconceivable distances from the parent cliff." Again, "I descended obliquely (from the Donkiah Pass) down a very steep slope of 35° over upwards of 1000 feet of debris, the blocks of which were so loosely piled on one another, that it was

necessary to proceed with the greatest circumspection, for I was alone, and a false step would almost certainly have been followed by breaking a leg. The alternate freezing and thawing of rain amongst these masses must produce a constant downward motion in the whole pile of debris (which was upwards of 2000 feet high), and may account for the otherwise unexplained phenomena of continuous shoots of angular rocks reposing on very gentle slopes in other places."]

46. It is also by the action of frost that avalanches, glaciers, and icebergs are formed on mountains above the snow-line and in arctic regions: the *avalanche* of snow and ice, which, losing its coherence, is launched from the mountain-side, carrying masses of rock and soil and trees before it—the *glacier*, or ice-river, that gathers in the mountain-glen above, and slowly grinds its way to the valley below, smoothing the rocks in its passage, and leaving as it melts away its lateral and terminal ridges of gravel and debris, technically termed "moraines"—and the *iceberg*, detached by fracture from the projecting glacier of some arctic shore, that floats its burden of rock and gravel to warmer latitudes, there to drop them as it melts away on the bottom of the ocean. In the study of frost-operations, whether among the cliffs and gorges of Alpine mountains or along the shores of the Arctic Ocean, the observer discovers at once an important cause of present change, and a key to the solution of some of the most interesting of geological problems.

[Many of the *bergs* which drift out to sea, having been the extremities of glaciers while in attachment to the coast, are loaded with huge *angular* fragments of rock and other debris; and many of the *floes*, having been ground or shore ice, lift with them immense masses of *water-worn* shingle and gravel. Thus, as both melt away, the bottom of the ocean must be strewed with very heterogeneous and curiously assorted material. Nay, icebergs have been encountered in the North Sea covered or interstratified with ancient soil, among which were the bones of mammoths and other extinct animals, still further confusing the nature of their deposits by mingling the remains of an existing fauna (rein-deer, musk-ox, arctic bear, &c.) with one of a much higher antiquity.]

47. The chemical action of the atmosphere (composed of oxygen, nitrogen, and carbonic acid) is observable less or more on all exposed surfaces. Its gases, partly by their own nature, and partly by the moisture diffused through them, exert a wasting or *weathering* influence on all rocks—softening, loosening, and crumbling them down, to be more readily borne away by currents of wind and water. Carbonic acid acts specially on all rocks containing lime; oxygen rusts or oxidises those impregnated with iron; moisture insinuates itself everywhere; and thus in a few years the hardest rock exhibits a weathered or wasted surface. Particle after particle is loosened; film after film falls away; a new surface is exposed to new waste; and in course of

ages the boldest mountain-mass yields to this silent and almost imperceptible agency. In such instances as the above, the atmosphere acts *directly* as a chemical agent; where it impregnates rain and other water with its gases, and these operate within the crust as springs, it acts *indirectly*, though not less efficiently.

48. As the diffuser of light, heat, and moisture — and these could not be diffused around our globe without the intervention of an aërial medium — the atmosphere exercises important influences on vegetables and animals, making the surface teem with life in one region, and rendering it a barren waste in another. In this function it acts *indirectly* as a geological agent, the accumulations of vegetable and animal exuviæ (*exuviæ*, the cast-off products or remains) being the results which modify or appear in the composition of the rocky crust. Those products vary, of course, both in kind and exuberance, according to the amount of light, heat, and moisture received at any portion of the earth's surface, and these again are regulated by the conditions of the atmosphere. A dense moist atmosphere conducts and diffuses heat more perfectly than a dry and highly rarified one; an increase of temperature is accompanied by a more rapid evaporation, and a consequent increase in the diffusion of moisture; and these are the conditions most favourable, other things being equal, to the exuberance of vegetable and animal life. Again, such an increase of heat and moisture would be followed by heavier rain-falls, these by more frequent and larger rivers; and thus, geological results of a purely mechanical kind would be greatly augmented. In fact, the reception of light and heat from the sun, their diffusion through the atmosphere, their action on the waters of the globe, and the combined influence of the whole on vegetable and animal existence, forms one of the great primary departments of natural science, and the student cannot too soon familiarise himself with reasonings on their mutual bearings and results.

Aqueous Agencies.

49. The modifying causes arising from the operations of water are, like those concerned with the atmosphere, universal and unceasing. This aqueous agency manifests itself most prominently in the mechanical effects of rains, springs, streams, rivers, waves, tides, and oceanic currents. Every shower that falls exerts a degrading or wasting influence on rocks, soils, and all exposed surfaces. By entering the pores of rocks and soils, rain softens and loosens their cohesion, and thus renders them more easily

acted on by currents of wind and water. Land-floods or freshets also arise from rains, the melting of snow, and from hail-storms; and the periodical rains of the tropics produce inundations and similar phenomena. The fall of rain varies in different countries, and, of course, will be attended with proportional results. In the British Islands it ranges from 24 to 60 inches, or has an average of about 36 inches; while in tropical countries the mean annual fall is upwards of 200 inches—229 inches having been noted in Dutch Guiana, 276 in Brazil, 302 at an elevation of 4200 feet in the Western Ghauts, south of Bombay; and in the Khasia mountains, at the head of the river-flats or Jheels of Bengal, upwards of 600 inches, or 50 feet, have been registered by various observers. At the same place, Dr Hooker has recorded 30 inches in twenty-four hours; 21 inches have been noted at Cayenne during the same period; and 23 inches are not uncommon near Port Jackson in New South Wales. Accustomed to the gentle rains of our own island, we can scarcely form an estimate of the changes produced by such sudden and enormous falls on the surface-soil and river-courses of tropical countries.

50. Streams and rivers—in fact, all water-currents—act chiefly in a mechanical way, and their influence depends partly on the nature of the rocks over which they run, the rapidity of their flow, and the size or volume of water. If the rocks over which they pass be of a soft or friable nature, they soon cut out channels, and transport the eroded material in a state of mud, sand, and gravel to the lower level of some lake, to their estuaries, or to the bed of the ocean. Their cutting as well as transporting power is greatly aided by the rapidity of their currents; hence the power of mountain torrents compared with the quiet and sluggish flow of the lowland river. It has been calculated, for example, that a velocity of 3 inches per second will tear up fine clay, that 6 inches will lift fine sand, 8 inches sand as coarse as linseed, and 12 inches fine gravel; while it requires a velocity of 24 inches per second to roll along rounded pebbles an inch in diameter, and 36 inches per second to sweep angular stones of the size of a hen's egg. During periodical rains and land-floods the currents of rivers often greatly exceed this velocity; hence the tearing up of old deposits of gravel, the sweeping away of bridges, and the transport of blocks many tons in weight—an operation greatly facilitated by the fact that stones of ordinary specific gravity (from 2.5 to 2.8) lose more than a third of their weight by being immersed in water. Nor is it the mere velocity of rivers which produces their eroding or cutting power, but the amount and nature of the debris carried down by their torrents—every pebble and block of

shingle rubbing and striking and grinding still deeper and deeper the channels down which they are borne. The geological effects of rivers on the crust is thus of a twofold nature—viz., to waste and wear down the higher lands, and then to bear along the waste material and deposit it in valleys, in lakes, or in the ocean, in the state of mud, clay, sand, or gravel. By such deposits lakes are silted or filled up, and become alluvial valleys; estuaries converted into level plains; and even large tracts reclaimed from the sea.

51. Springs, which are discharges of water from the earth, act both mechanically and chemically on the crust, internally as well as externally. Hot or thermal springs, and those whose waters are impregnated with carbonic acid, for example, act chemically and internally by dissolving the rocks through which they percolate in the crust of the earth; and when they reach the surface, they act externally by depositing the matter which their waters held in solution. Such springs are common all over the globe, are known as *mineral springs*, and generally indicate the kind of rock or mineral through which they have percolated. Thus some are saline, or contain salt; some chalybeate, or contain iron (*chalybs*, iron); some siliceous, or contain flint (*silex*); some calcareous, or contain lime (*calx*); while others give off sulphurous vapours, or are impregnated with various mineral admixtures. Such springs act chemically in dissolving and re-depositing mineral matter; and they act mechanically in wearing and transporting like all running water. We know little of the chemical changes taking place among the rocks of the earth's crust; but, estimating from the frequency of mineral springs and their ceaseless action, the results cannot be inconsiderable. Internally, most of the subterranean caverns and chasms in limestone districts are caused by this chemical action of spring water; and externally such formations as the travertine limestone of Italy, and the siliceous sinter of the Iceland geysers, are produced by the same agency. Even vapour of a high temperature is capable of dissolving silica; and Mr Darwin alludes to an instance in Terceira (one of the Azores), where steam, issuing from fissures in the trachytic rock, gradually softens and decomposes the crystalline mass till the whole is reduced to a white chalky clay, with which the inhabitants whitewash their houses.

52. As with springs and rivers, so with waves, tides, and ocean-currents: they all waste and wear away the sea-cliffs in exposed districts, and deposit the degraded material in the state of mud, sand, gravel, and shingle in some sheltered locality. Waves, which are the immediate offspring of the winds, are produced

more or less on all expanses of water—their dimensions varying with the depth and extent of water, and with the force of the wind which sets them in motion. The degrading power which they exert on any particular coast varies, of course, with their own magnitude as well as with the nature and position of the rocks exposed to their action. A coast line consisting of soft clays and marls will suffer more waste than one composed of sandstones and shales, and these again will yield more readily than cliffs of basalt and granite. Further, strata that dip seaward, and present, breakwater-like, their natural slopes to the action of the waves, will suffer less than those whose outcropping edges are presented to the storm; and those traversed by rents and fissures will fall away mass by mass as they are undermined, while those not so traversed will long resist in solid continuity. Whatever the modifying circumstances, or whatever the rate of waste, we see enough of wave-action along our own coasts to convince us of the geological importance of this set of agencies, operating as they incessantly do along the entire shore-line of the all-encircling ocean. Tidal and other oceanic currents, though not so universal in their operations as waves, are also important geological agents. Sweeping with greater or less velocity along exposed shores and over shallow shoals, they exert, like all other currents, a wasting influence; but it is chiefly in their powers of transport that they manifest their action—all the debris borne into the ocean by rivers, produced by the erosion of waves, showered upon it by volcanoes, or arising within it from the growth and decay of plants and animals, being carried hither and thither, and assorted by their ebb and flow.

53. By the operations of water, as described in the preceding paragraphs, vast changes have been effected, and are still in process of being effected, on the surface of the globe. There is scarcely a country in the world which does not present numerous glens and ravines and river-channels, all cut through the solid strata by the action of water; hence known as *valleys of erosion* (*erosus*, gnawed or wasted away). The rocky matter thus ground down is borne away by every flood, in the state of mud, sand, gravel, and shingle; and when the water comes to rest, these fall to the bottom as *sediment* (*sedere*, to settle or sink down). Every person must have observed the rivers in his own district, how they become muddy and turbid during floods of rain, and how their swollen currents eat away the banks, deepen the channels, and sweep away the sand and gravel down to some lower level. And if, during this turbid state, he will have the curiosity to lift a gallon of the water, and allow it to settle, he will be astonished

at the amount of sediment or solid matter that falls to the bottom. Now, let him multiply this gallon by the number of gallons daily carried down by the river, and this day by years and centuries, and he will arrive at some faint idea of the quantity of matter worn from the land by rivers, and deposited by them in the ocean. In the same way as one river grinds and cuts for itself a channel, so does every stream and rill and current of water. The rain as it falls washes away what the winds and frosts have loosened; the rill takes it up, and, mingling it with its own burden, gives it to the stream; the stream takes it up and carries it to the river; and the river bears it to the ocean. Thus the whole surface of the globe is worn and grooved and channeled—the higher places being continually worn down, and the wasted material carried to a lower level. As on land, so along the sea margin there is a perpetual conflict, as it were, between the powers of waste and accumulation—the opposing cliffs being gradually worn down, and the resulting debris strewn along the shore or sea-bottom at a lower level.

54. By processes such as these, lakes are silted up and become marshes or plains, and estuaries and shallow seas are converted into tracts of alluvial land. The *delta* of the Nile (so called from the Δ, or delta-like shape of the space enclosed by the two main mouths of that river), the sunderbunds or river-islands of the Ganges, the swamps of the Mississippi and Amazon, are examples of such deposits on a large scale; but every stream and current of water, however insignificant, is less or more performing a similar operation. Such deposits, when examined, are found to consist of layers of mud, vegetable drift, clay, sand, and gravel, containing, in greater or less abundance, the remains of plants and animals peculiar to the country through which the transporting rivers flowed, and always in a notable degree the exuviæ of the corals, shells, crustacea, fishes, and other creatures which inhabited the sea of deposit. In this manner layers or strata of sedimentary matter are forming at the present day, and in like manner must they have been formed during all past ages of the world. The present, thus, explains to us the past; a knowledge of the past and present enables us to foretell, in some measure, the conditions of the future.

55. On the whole, then, it may be set down as a geological axiom, that the tendency of all aqueous agency, whether operating as springs and rivers, or as tides, waves, and ocean-currents, is to wear down the higher portions of the earth's crust, and transport the material as sediment to some lower level. This sedimentary matter being merely floated in the current (or

mechanically suspended, as it is termed, in contradistinction to a *chemical* solution), the moment the water assumes a state of quiescence it begins to fall to the bottom. The heavier bodies, as shingle and gravel, fall first, next the finer particles of sand, and ultimately the light flocculent mud or clay. In this way we can account for the gravelly beach of one district, the sandy shore of another, and the muddy bottom of a third. The clayey mud of the great Chinese rivers (borne down, it has been estimated, at the rate of 2,000,000 cubic feet every hour) is carried far out into the Yellow Sea, thereby giving it a name, and rapidly converting it into a shallow basin; the turbid waters of the Ganges, carrying down, it is said, 700,000 cubic feet per hour, discolour for many leagues the Bay of Bengal; and the mud of the Amazon is observable many hundred miles out in the Atlantic. Thus, year after year, a portion of the Himalayan Mountains is deposited in the Bay of Bengal, and the waste of the Andes strewed along the bottom of the Atlantic, there to be re-formed into new strata, and constitute, it may be, the material of future continents.

Organic Agencies.

56. The organic causes tending to modify the crust of the globe are those depending on animal and vegetable growth. The term *organic* (from the Greek *organon*, a member or instrument) is applied to plants and animals, as being supplied with certain organs or members for the purposes of nutrition and growth. Their structure is said to be *organic*, and they are termed organised bodies, in contradistinction to minerals, which are inorganic, and whose increase takes place by external additions, and not through the instrumentality of any peculiar organs. As geological agents, vegetables and animals act either directly or indirectly—directly in the formation of new matter, as peat-moss and coral-reefs, and indirectly in protecting the surface from atmospheric or aqueous waste, as in the herbage that covers the soil. The operations of organic agency are ceaseless, and all but universal—there being no spot on the earth's surface, except, perhaps, the snow-clad mountain-peak and the ice-bound islands of the polar regions, entirely devoid of life; and even there peculiar forms seem to manifest a periodical development. The temperate and tropical zones, however, are the great theatres of life—generic as well as numerical variety resulting from favourable conditions of light, heat, and moisture.

57. The growth and decay of vegetables are yearly adding to

the soil, at the same time that they protect the surface from the wasting action of rain, frost, and the like. One of the great aids to rapid disintegration in arctic countries and in high mountain districts is the absence of a superficial covering of vegetation—a covering which, on the other hand, protects the tropical soil from the wasting effects of the heavy rains which periodically fall in these latitudes. Accumulations of plant-growth form peat-mosses, jungle-thickets, cypress-swamps, and the like; and the spoils of forests and the vegetable drift of rivers form raft-like masses, all of which are yearly adding to the solid matter of the globe. Coal, as will afterwards be seen, is but a mass of mineralised vegetation; and, under favourable conditions, submerged peat-mosses, forests, and vegetable drift, would constitute similarly mineralised deposits. As familiar instances of vegetable agency we may point to the peculiar plants (the sea-reed, lyme-grass, sea-pine, &c.) that spring up on the newly-formed sand-dunes by the sea-shore, and protect the surface from being blown and scattered about by the winds; to the peat-bogs of Ireland, Scotland, Holland, and other countries, formed by the growth of reeds, rushes, equisetums, carex, sphagnum, and the like; to the pine-rafts yearly floated down by the Mississippi; to the cypress-swamps of North America; to the jungle-growth of tropical India; and to the mangrove thickets that bind and conserve the mud islands of the Ganges and Niger. As vegetable growth is specially influenced by heat, light, moisture, and conditions of climate, so in certain regions will its geological influence be more felt than in others. Every region, however, has its own peculiar flora; and such peculiarities must have characterised less or more the vegetation of all former epochs, according as the plants flourished under the tropics or in the temperate zone, in the marshy swamp or on the arid plain, under the open air on land, or under the waters at varying depths along the shores of primeval oceans.

58. The mode in which animals tend to affect the crust of the earth is chiefly by adding their waste secretions or coverings. It is true that the bones and other remains of the larger animals are often buried in the mud of lakes and estuaries—there in time to form solid petrifactions, and to leave records of the past life of the globe; but such results are lithologically trifling compared with shell-beds, infusorial accumulations, and coral-reefs. Thus gregarious molluscs—as oysters, cockles, and mussels—live in beds of considerable thickness, and, if entombed amid the silt of estuaries, will in time constitute beds of shelly limestone, like those occurring among the older strata. For miles along certain coasts

we meet with thick accumulations of drifted shells: such accumulations we find in all raised beaches and marine silt; and many of the so-called shell-marls of our ancient lakes are almost wholly composed of the shells of lymnea, paludina, planorbis, and other fresh-water genera. The recent discoveries of the microscope have shown that many accumulations of whitish mud in lakes and estuaries, as well as certain deposits in bogs and valleys, now silted up, are almost wholly composed of the siliceous and calcareous coverings of infusorial organisms (so called from being abundantly found in putrid vegetable infusions). We say infusorial *organisms*, for it is still matter of dispute among microscopists how many of these minute forms of existence should be classed with the vegetable, and how many with the animal kingdom. Whatever their real nature, they are produced with extreme rapidity; and their flinty and limy cases (many thousands of which are contained in a cubic inch), being aggregated in countless myriads, constitute thick layers, as in the estuary of the Elbe, in the plains of the Amazon, and in many of our own bogs; just as the mountain-meal (berg-mahl) of the Swedes, the edible clay of the American Indians, and the polishing slate of Tripoli and Bohemia, are analogous deposits of earlier dates. Besides these infusorial organisms, the calcareous shells of microscopic *foraminiferæ* are also adding largely to the solid or rocky matter of the globe. In all deep-sea soundings, whether in the Indian, Atlantic, or Pacific Ocean, the lead invariably brings up thousands of these minute shells, and over extensive areas the muddy deposit seems to be entirely composed of such remains. In the North Atlantic, for example, the United States ship Dolphin made many soundings, varying from 1000 to 2000 fathoms, and, according to Professor Bailey, the matter brought up by the lead "did not contain a particle of gravel, sand, or other recognisable unorganised mineral matter, but was almost entirely made up of the calcareous shells of minute foraminiferæ." Combining these results with others obtained from soundings in the western portion of the Atlantic, Mr Bailey arrives at the still broader conclusion, "that the bottom of the North Atlantic, as far as examined, from the depth of about 60 fathoms to that of more than two miles (2000 fathoms), is literally nothing but a mass of microscopic shells." When treating of the older rock-formations we shall see what an important part these minute creatures (infusoriæ and foraminiferæ) have played in adding to the solid matter of the globe; and were the accumulations now taking place in our seas and lakes and rivers investigated with proper care, we should in all likelihood discover them

still playing as important a part in the formation of solid rock-matter.

59. By far the most notable, as it is undoubtedly the most wonderful, exhibition of animal agency—or rather of animal-chemical agency—is that of the coral zoophyte. Endowed with the power of secreting lime from the waters of the ocean, the coral animalcule rears its *polypidom*, or rocky structure (*polypus*, and *domus*, a house), in the warmer latitudes of every sea—and there constructs reefs and barriers round every island and shore, where conditions of depth and current are favourable to its development. Many of these reefs extend for hundreds of leagues, and are of vast thickness, reminding one of the strata of limestone belonging to the older formations. The true reef-building zoophyte is apparently limited in its range of depth, operating only where perpetually covered by the tide, and downwards to eighteen or twenty fathoms. Within this range it is ceaselessly active,—elaborating lime from the ocean, and converting it into a home for itself and its myriad progeny. Let any one examine a branch of common madrepore coral, count the number of cells or pores in it, remember that each pore is the abode of an independent but united being, and then reflect on the thousands of miles of coral reef now in process of formation, and he will be lost in wonder at the numerical exuberance of animal life. The reef-building corals (for there are corals which live separately or in limited groups and at vast but variable depths) are of various families and genera—the more abundant, according to Darwin, being the *Madrepores*, *Astræas*, *Porites*, *Meandrinæ*, and *Nullipores* at moderate depths, and the *Millepores*, *Seriatopores*, and other delicate forms, at depths from fifteen to twenty fathoms. The reef-mass formed by their aggregate labours occurs also in all stages of development, from the living and growing branch to a compact and solid aggregation of limestone, scarcely to be distinguished from some of the softer marbles. Partaking of the elevation or depression of the sea-bottom, and being subject to the influence of the waves and breakers, a coral-reef is not a mere narrow ledge composed of various beautifully-formed corals, but a barrier of limestone more or less compact, mingled with sand, shells, sponges, sea-urchins, and other marine exuviæ, and often presenting a surface above the waves weathered and converted into soil capable of sustaining a scanty vegetation.

[It is customary to speak of coral-reefs as rising from unfathomable depths, and forming, as it were, independent islands in the expanse of ocean. It is true that detached corals and coral-drift have been brought up by the sounding-lead in almost every sea, and often at vast depths (Sir

J. Ross dredged living coral up 270 fathoms in 73° S. latitude); but the reef-building species seem to operate only within the limits above indicated. Should the bottom to which they are attached partake of a gradual elevation, they build outward and seaward to deeper water; and should it be undergoing depression, they build upward and upward without interruption, and thus present in course of ages a reef of vast extent and thickness. On the point of depth, Mr Darwin, who has made the formation of coral-reefs a subject of special observation and study, speaks decidedly as follows:—"Although the limit of depth, at which each particular kind of coral ceases to exist, is far from being accurately known, yet when we bear in mind the manner in which the clumps of coral gradually become unfrequent at about the same depth, and wholly disappear at a greater depth than twenty fathoms, on the slope round Keeling Atoll, on the leeward side of the Mauritius, and at rather less depth, both without and within the atolls of the Maldiva and Chagos Archipelagoes; and when we know that the reefs round these islands do not differ from other coral formations in their form and structure,—we may, I think, conclude *that in ordinary cases, reef-building polypifers do not flourish at greater depths than between twenty and thirty fathoms.*"——Respecting the rapidity of the growth of coral we have no very definite information. According to earlier authorities, the growth of a coral-reef is exceedingly slow, and some observations in the Red Sea and elsewhere would seem to favour this conclusion; but Mr Darwin, who cites instances of a ship's bottom being covered to the thickness of two feet in twenty months—of loose masses becoming firmly cemented by new growth in six months—and of a channel in Keeling Reef, through which a schooner was floated, being choked up in ten years—has arrived at the following conclusions:—"*First*, that considerable thicknesses of rock have certainly been formed within the present geological era by the growth of coral and the accumulation of its detritus; and, *secondly*, that the increase of individual corals and of reefs, both outwards or horizontally, and upwards or vertically, under the peculiar conditions favourable to such increase, is not slow, when referred either to the standard of the average oscillations of level in the earth's crust, or to the more precise but less important one of a cycle of years."]

Chemical Agency.

60. The modifying causes resulting from chemical action are numerous and complicated. Thus, the accumulation of the coral-reef is partly a chemical process; the operations of all mineral springs are more or less chemical; and many of the phenomena connected with volcanoes and earthquakes may arise from a similar source. The results of electric and magnetic forces, whether operating in the atmosphere, as in thunderstorms and the like, or silently among the solid substances of the crust, may be regarded as coming under this head; so that chemical agency, though one of the least perceptible, may in reality be one of the most general of modifying causes. Laying aside, in the mean time, the changes taking place in the interior of the rocky crust by which some strata are consolidated and hardened, others softened and dissolved away, metallic veins formed, and new compounds elaborated by the union of different substances, we shall

confine our remarks to those chemical results which chiefly appear on the surface.

[The student should early accustom himself to look beyond the mere *accumulating* effect of chemical action, and endeavour to become acquainted with the manner in which the constituent matters of rock-substances act and react upon each other. Thus, the alkalis and alkaline carbonates attack many rocks with great facility, removing first a portion of their silica, then a portion of their alumina, and subsequently also water, soda, potash, lime, and magnesia. From the researches of M. Delesse, it has been found that the action of the alkalis is greater—the larger the amount of silica a rock contains, the less crystalline their structure, and the less glassy quartz appears in their composition. Hence many volcanic and trappean rocks, as trachyte, obsidian, pearlstone, &c., are rapidly acted on, and fully 40 per cent of their mass removed, by the action of alkaline salts; and as the waters of infiltration always contain less or more of these salts, and as the amount increases with the depth at which the waters percolate, and the effect is increased by increase of temperature and pressure (as is seen in many mineral waters, geysers, &c.), there can be no doubt that the action of the alkalis or alkaline salts plays an important part in the chemical reactions which take place in the interior of our planet. Again, according to Bischoff, alkaline and earthy *sulphates* are reduced by carbonaceous substances in the wet way into *sulphurets*. For example, the so-called "fetid gypsum" is a sulphate of lime which has been partially converted into sulphuret of calcium by contact with organic matter in water. If a mineral water contains sulphates, proto-carbonate of iron, and organic matter, the conditions for the formation of sulphuret of iron are complete, and sulphuret of iron is actually formed in this way. As with these, so with many other instances that might (if space permitted) be readily adduced.]

61. The formation of coral-reefs, we have said, is partly a vital and partly a chemical process. The living matter is no doubt secreted by the polype, but its consequent consolidation into a compact rocky mass is the result of chemical action (through the percolation and transfusion of carbonated waters) among the particles of lime, of which the coral is almost wholly composed. The same sort of cohesion takes place among shell-beds and calcareous sands, often rendering them as hard and compact as ordinary building-stone. Deposits of limestone from what are termed calcareous or petrifying springs, are strictly of chemical origin, as are also the *stalactites* arising from the dropping of calcareous water from the roofs of caverns, and the *stalagmites* which incrust their floors. In this way are formed porous calcareous tufa or calc-tuff, compact calc-sinter (*sintern*, to drop), the travertin of Italy, and other calcareous aggregations. As with lime, so in like manner with flint or silex—many hot springs, like those of Iceland and the Azores depositing siliceous incrustations (*siliceous-sinter*) of considerable thickness, or permeating loose material, and binding them together with a hard flinty cement. Clay or alumina, sulphur, and other mineral matters, are also deposited

largely from springs, or arise as sublimations from fissures connected with volcanic action. Sulphurous mud-springs, indeed, are quite common in volcanic districts, and are incessantly discharging their contents in ravines and river-courses, or forming wide barren tracts of hardened mud and sulphur.

62. Deposits of salt, natron, and the like, are also of chemical origin; and these are to be found less or more in all tropical regions, and in many volcanic districts. Deposits of common salt (chloride of sodium) along the flat muddy shores of India, in the bottom of salt-lakes and the like, are familiar phenomena, and where continued year after year must in time acquire considerable thickness. Nitrate of soda and nitrate of potash are deposited in like manner in the shallow lakes of Africa and Asia, and in the deserted river-courses of South America; while most of the borax of commerce is derived from the lakes of Central Asia or the lagoons of Northern Italy. Under this head also may be classed all bituminous exudations and deposits, as petroleum and asphalt, which either impregnate the soil and gravel through which they percolate, or form independent deposits, as the pitch lakes of Trinidad and Texas.

Igneous or Volcanic Agency.

63. The last and most important of the modifying causes to be noticed, are those depending on igneous or volcanic agency (*ignis*, fire). The operation of water, whether in the form of rain, rivers, or waves, is to wear down the higher portions of the earth's crust, and transport the matter to lower localities—thus tending to reduce all to one smooth and uniform level. This equalising tendency of water is mainly counteracted by the operations of fire—the earthquake and volcano breaking up, elevating, and producing that diversity of surface so indispensable to variety in vegetable and animal life. These two forces—the aqueous and igneous—may be considered as antagonistic to each other, and to them may be ascribed the principal modifications that have taken or are still taking place in the crust of the globe. As the one tends to degrade and wear down, so the other tends to elevate and reconstruct; and though the force exerted by either may vary at different epochs, still the general result is the maintenance of a habitable terraqueous surface. Igneous agency or *Vulcanism*, as depending on some deep-seated source of heat with which we are but little acquainted, manifests itself in three grand ways—viz., in Volcanoes, in Earthquakes, and as a Gradually Ele-

vating Force. In these exhibitions, igneous agency acts *chemically* in the fusion and production of new rock-compounds, and *mechanically* in fracturing, depressing, and elevating.

64. The effect of Vulcanism or internal igneous force is to elevate either by simple expansion and upheaval of the crust, or by the repeated accumulations of matter ejected from the interior. Both of these modes are abundantly evident in nature; and one can scarcely credit the amount of argument that has been expended to prove that volcanoes were either all "craters of elevation" or all "craters of eruption," as if the two modes were not ever coincident and concomitant phenomena. We can readily conceive of large areas of the earth's crust being fractured and borne up by volcanic force from beneath, and in this way many of our mountain-chains and hill-ranges have at first been formed. At certain places openings or *craters* occur (so called from their cup-like form—*krater*, a cup or bowl), and from these are ejected at intervals molten lava, fragments of rock, ashes, dust, hot mud, and various gaseous exhalations. Flowing from the crater over the surrounding country, the lava, after cooling, frequently forms thick layers of rocky matter, varying in compactness from hard basalt to open and porous pumice-stone. Ashes, dust, and mud accumulate in a similar manner, eruption after eruption adding to the height of the mountain, and ultimately giving to it a conical form. In this way have the cones of Etna, Vesuvius, and Hecla been formed; and in this way have these eruptions modified the surrounding country, filling up valleys, creating crags and cliffs, enveloping fields, and burying cities, as in the case of Pompeii and Herculaneum. As with these within the historic period, so with upwards of two hundred others in various parts of the globe; and looking at many of our older hills and mountain-ranges, we discover abundant proofs of a similar origin and mode of formation. As yet we have spoken of volcanoes as taking place only on land; but we have also evidence of their occurrence in the ocean, creating shoals and islands like many of those in the Pacific. In the one case, volcanoes are termed *sub-aërial*, in the other *sub-aqueous*. When taking place under water, the volcanic discharges of lava and ashes will be interstratified and mingled with the sedimentary matter of the ocean—an occurrence we shall afterwards find very common among the older rock-formations; and still more complex phenomena will be presented when the eruptions occur among snows and glaciers and icebergs, as do those of Mount Erebus in the Antarctic Ocean. On the whole, as there is no modifying cause so sublime in its operations as volcanic agency, so likewise there is none more complicated or puzzling in

its results. Now we have outbursts of molten lava, here cooling rapidly into a vitreous-looking mass (obsidian), there cooling slowly, and forming granular and crystalline rocks, like basalt and greenstone (trachyte); at another period discharging light cellular slag-stone (pumice); at a third showering abroad clouds of dust and ashes over the land and adjoining seas; again casting forth huge rock-masses and fragments (volcanic bombs); and anon giving rise to hot springs, mud springs, exhalations of sulphur, steam, and other gaseous products.

65. Earthquakes, which are intimately associated with volcanoes, and but varied expressions of the same force, produce modifications of the earth's crust chiefly by fracture, subsidence, and elevation. During their convulsions the level plain may be thrown into abrupt heights, rent with chasms and ravines, or even be submerged beneath the ocean. Their general tendency is, therefore, like that of volcanoes, to diversify the surface of the globe, and to render irregular what aqueous agency is perpetually striving to render smooth and uniform. During violent convulsions, extensive alterations are sometimes produced on the face of a country; and of such changes in Southern Italy, Iceland, India, the West Indies, Mexico, and other volcanic regions, we have frequent and abundant record within the historical era. Even within the present century, we know that a large tract at the mouth of the Indus was submerged, while a new district was raised from beneath the ocean; that the coast of Chili for many leagues was permanently elevated from six to ten feet; and that in the West India Islands, harbours have been sunk, towns destroyed, and rivers changed from their former courses. The operations of earthquakes must have been similar in all time past, and to them must be ascribed many of the fractures, dislocations, and contortions, so prevalent among the earlier rock-formations of the globe.

66. The gradually-elevating forces connected with igneous agency are less obvious than the volcano and earthquake, but not on that account the less important or general. At present it is known, from repeated observation, that the shores of the Baltic are gradually rising above the waters, at the rate, it is estimated, of four feet in a century; the shores of Siberia, as well as of all the islands within the Arctic Circle, are fringed with numerous recent terraces; and large tracts along the eastern and south-western coasts of South America exhibit similar uprises. Such uprises, not being very perceptible, are apt to be under-estimated, or even disregarded; but when we cast our eye along the shores of our own island, and discover various ancient

beaches or shore-lines stretching along above the present sea-level, at elevations varying from ten, twenty, forty, and sixty, to one hundred feet and upwards, we are then prepared to admit how extensively the appearance and conditions of the globe must be modified in course of ages by these slowly-gradual but gigantic manifestations.

["At Lima," says Mr Darwin, in his *Geological Observations in South America*, "the elevation has been at least 85 feet within the Indio-human period; though since the arrival of the Spaniards in 1530, there has apparently been a slight sinking of the surface. At Valparaiso, in the course of 220 years, the rise must have been less than 19 feet; but it has been as much as from 10 to 11 feet in the 17 years subsequently to 1817, and of this rise only a part can be attributed to the earthquake of 1822, the remainder having been insensible, and apparently still (1834) in progress. At Chiloe the elevation has been gradual, and about 4 feet in four years. At Coquimbo, also, it has been gradual, and in the course of 150 years has amounted to several feet. The sudden small upheavals, accompanied by earthquakes, as in 1822 at Valparaiso, in 1835 at Concepcion, and in 1837 in the Chenos Archipelago, are familiar to most geologists, but the gradual rise of the coast of Chiloe has been hardly noticed; it is, however, very important as connecting together those two orders of events—viz., the gradual and sudden."]

67. Nor is it alone the configuration and extent of the terrestrial surface that are affected by this process; we know that the generic distribution of plants and animals is governed, in a great measure, by altitude above the sea; and one can readily perceive how such gradual uprises of the land must be gradually changing the character and distribution of the life upon its surface. Nor is it terrestrial existence alone that is influenced by such upheavals: the sea-bottom is partaking of the same uprise, and marine life is even more sensitive than terrestrial to changes of depth and sea-bottom. Every zone, from the shore daily covered by the tides to the greatest vital depths, is characterised by its own peculiar sea-weeds and shell-fish, and these must necessarily be influenced, in their kind and distribution, by every elevation and submergence of the sea-bottom they inhabit. Thus, in the British seas, naturalists point out four great zones of life—the Littoral, the Laminarian, the Coralline, and Coral. The *Littoral* lies between high and low water mark (varying in extent according to the rise and fall of the tide and the shallowness of the shore), and is characterised, as the bottom may be rocky, sandy, or muddy, by such molluscs as the periwinkle, limpet, mussel, cockle, razorshell, &c., and by such plants as the bladder wrack, dulse, and carigeen. The *Laminarian* commences at low-water mark, and extends to a depth of from 40 to 90 feet, and is characterised, as its name implies, by the broad waving sea-tangle and larger algæ, by star-fishes, the common echinus, by tubularia,

modiola, and pullastra. The *Coralline* extends from 90 to about 300 feet in depth, and is, in our latitudes, the great theatre of marine life; the common sea-weeds cease, and corallines luxuriate; the ordinary shore shells disappear; and buccinum, fusus, trochus, venus, pécten, and the like, abound. The *Coral* zone, as its name implies, is the region of the calcareous and stronger corals, and extends from 300 to 600 feet—a depth rarely found in true British seas—but where found characterised by forms of star-fish, cidaris, and brachiopod mollusca, which cannot exist in shallower waters. Any derangement, therefore, of these zones caused by volcanic or earthquake disturbance—whether sudden or gradual—would necessarily be followed by a change in their fauna and flora, perhaps by a total extinction of many genera and species from these waters. As along our own shores, so all over the globe—the laws of organic development and distribution vary with external physical conditions; and with the numerous causes which may alter and modify these conditions, the student of geology cannot too soon render himself familiar.

NOTE, RECAPITULATORY AND EXPLANATORY.

68. In the preceding chapter we have given a general outline of the causes now tending to modify the crust of the earth; that is, of the principal agencies concerned in the production of all geological change. These, we have said, are the Atmospheric, the Aqueous, the Organic, the Chemical, and the Igneous or Volcanic. By one or other of these agencies, or by a combination of them, are all the changes now taking place on the globe effected; and as we are warranted in concluding that these agents have similarly operated through all previous time, so to them must be ascribed the formation and structure of the solid crust. Rains, winds, and frosts must have always weathered and worn down; springs, streams, and rivers must have always cut for themselves channels, and transported the eroded material to lakes and seas, there to be spread out in layers or strata; and in these accumulations must the remains of plants and animals have been entombed, some swept from the land, and others buried as they lived in the waters. In this way, and by calling in the aid of chemical and organic agency to explain the occurrence of certain mineral deposits and accumula-

tions of vegetable and animal growth, we can account for the formation of all rocks which occur in layers or strata. On the other hand, as volcanic agency now breaks up the crust of the earth, elevating some portions and submerging others, and anon casting forth, from rents and craters, masses of molten matter, and showers of dust and ashes, so in former times must the same agency have fractured and contorted the solid strata, and cast forth molten matter, which, when cooled down, would form rock-masses, in which no layers or lines of deposit could appear. Besides modifying the earth's crust by upheaval and disruption, volcanic agency also produces a peculiar class of rocks; and these are found abundantly in all regions, from the recent lavas of Etna and Vesuvius, to the basalts, greenstones, and granites of our own hills.

69. We have thus, on and within the globe, a variety of agents ceaselessly active, and ceaselessly productive of change. The result of their operations is, and has ever been, the production of new rocks and new rock-arrangements; and the more we know of the operations, the better will we be able to appreciate their results. In the words of Sir Henry De La Beche: "As geological knowledge advances, the more evident does it become that we should first ascertain the various modifications and changes which now take place on the surface of the earth, carefully considering their causes, and then proceed to employ this knowledge, so far as it can be made applicable, in explanation of the facts seen in connection with the geological accumulations of prior date. This done, we should proceed to view those not thus explained, with reference to the conditions and arrangements of matter which the form of our planet, the known distribution of its heat, the temperature of the surrounding space, and other obvious circumstances, may lead us to infer would be probable during the lapse of geological time." Than this there is no other key to the interpretation of the terrestrial record; and to ascribe what we cannot thus explain to "catastrophes," "cataclysms," and "revolutions of the globe," is but to confess our inability to comprehend the phenomena in question. Law is operating everywhere, and where we fail in tracing its connection, it is better to rest satisfied with a faithful description of facts, than do violence to nature by appeals to the reign of disorder and confusion. The student cannot, therefore, pay too much attention to this department of his science; and luckily for his progress it is treated in admirable detail by Sir Charles Lyell in his *Principles of Geology*, and by Sir Henry De La Beche in his *Geological Observer*—works devoted exclusively to a consideration of the operations and changes now taking place on the crust of our planet.

IV.

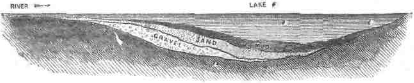
GENERAL ARRANGEMENT AND RELATIONS OF THE MATERIALS COMPOSING THE EARTH'S CRUST.

70. The terrestrial crust accessible to human research is composed of solid substances, all known to the geologist by the name of *rocks*—these rocks the products of the operations described in the preceding chapter. No matter whether in the state of soft and yielding clay, of incoherent sand and gravel, of dull earthy chalk or sparkling crystalline marble, of friable sandstone or of the hardest granite—all are spoken of as "rocks" and "rock-formations." In this sense the term *rock* is purely technical, and differs from the ordinary application of the word, which refers more particularly to hard and indurated masses. The crust of the earth, then, from the superficial soil to the limit of the greatest accessible depth, consists of rocks; and to ascertain how these are arranged, of what they are composed, and what their general distinguishing features, is the object of the present chapter. It must be obvious that without such knowledge it would be impossible to make any systematic classification of these materials, so as to arrive at definite notions respecting the causes and conditions that prevailed on the crust of the globe at the time of their formation.

Stratified or Sedimentary Rocks.

71. Judging from the operations of the modifying causes explained in the preceding chapter, one would naturally infer that all matter deposited as sediment from water will be arranged in layers along the bottom. Fine mud and clay readily arrange themselves in this manner, and sand and gravel are also spread out in layers or beds more or less regular. In course of time a series of beds will thus be formed, lying one above another in

somewhat parallel order, thicker, it may be, at one place than another, but still preserving a marked horizonality, and showing distinctly their lines of separation or deposit. Thus the miscellaneous *debris* (a convenient French term for all waste or worn material, wreck or rubbish) borne down by a river, will arrange itself in such layers along the bottom of a lake—the shingle and gravel falling first to the bottom, next the finer sand, and, lastly,



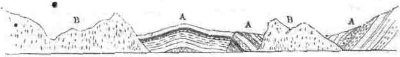
Stratified Arrangement of Sediment.

the impalpable mud or clay, as represented in the preceding diagram. As in lakes, so also in estuaries and seas; and as by the agency of rivers, so in like manner by the action of waves, tides, and ocean-currents, which are ceaselessly abrading the sea-coast in one district, and transporting the debris to another, where it is spread out in layers, all less or more horizontal. In process of time, according to the matter of which they are composed, the degree of pressure to which they are subjected, and the amount of chemical change their particles may undergo, these layers become hard and stony—sand being consolidated into sandstone, gravel into conglomerate, mud into shale, and so on of other ingredients. As at present so in all time past similar deposits in water must have taken place; and one cannot examine the face of a quarry, a sea-cliff, or railway-cutting, without observing how very generally the rocks are arranged into beds and layers. These layers are technically known as *strata* (plural of *stratum*, strewn or spread out); hence all rocks arranged in layers—that is, arising from deposition or sediments in water—are termed *aqueous*, *sedimentary*, or *stratified*. Here, then, we have one great division of the rock-materials composing the crust; namely, those arranged in strata, and hence presumed to have derived that arrangement from the ordinary sedimentary operations of water.

Unstratified or Igneous Rocks.

72. On the other hand, when we examine the rocky matter ejected from volcanoes, we observe no such lines of deposit, and no such horizontality of arrangement. In general, they burst

through the stratified rocks, or spread over them in mountain masses of no determinate form—here appearing as walls, filling up rents and chasms—there rising up in huge conical hills—and in another region flowing irregularly over the surface in streams of lava, which, when cooled, form a rock less or more compact, and not unfrequently of crystallised texture. When such rocks are quarried or cut through, they do not present a succession of layers or strata, but appear in *amorphous* masses; that is, masses of no regular or determinate form (*a*, without, and *morphê*, form or shape). Thus, in connection with the stratified rocks, they present something like the annexed appearance,—A A A being stratified or sedimentary rocks lying bed above bed; B B being the igneous, rising up through them in massive and irregular forms.



Stratified and Unstratified Rocks.

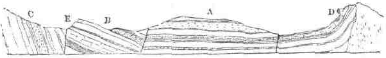
Referring to their origin, they are spoken of as *igneous* or *volcanic;* and in contradistinction to the aqueous rocks, they are termed the *unstratified.* We have thus, in the crust of the globe, two great divisions of rocks, the STRATIFIED and UNSTRATIFIED—the one depending on the operations of water, the other resulting from the operations of fire; and, as we shall afterwards see, to one or other of these divisions do all rock-formations belong, however much broken up, displaced, and contorted, or how great soever the changes that have subsequently taken place in their mineral composition.

[In the earlier geological works the student will find the terms *stratified, sedimentary, aqueous,* and *Neptunian* (Neptune, god of the ocean), indiscriminately applied to such rocks as evidently owe their origin to the operations of water; and, on the other hand, *unstratified, eruptive, igneous* or *pyrogenous,* and *Plutonic* (Pluto, god of the lower regions), applied to those that have resulted from the operations of fire, or are the products of igneous fusion.]

Relations of Stratified and Unstratified Rocks.

73. Having been spread or strewn over the bottom of seas and lakes in the state of sediment, the original position of the stratified rocks must have necessarily been less or more horizontal. A bed of mud, for example, may be thicker in one part than in another, or it may thin out and altogether disappear, its place being taken by a deposit of sand or gravel; but still its general deposition is

flat or horizontal. The stratified rocks, when broken up by earthquakes and volcanoes, will lose this horizontality, and be thrown into positions more or less inclined and irregular. Nay, by the violent and repeated operation of volcanic forces, they may be thrown on edge, may subside in basin-shaped troughs and hollows, or be bent and contorted in the most strange and fantastic manner. Such appearances are frequent in sea-cliffs, in the sides of ravines, in railway-cuttings, and in quarries; and geologists speak of such faces or exhibitions of strata as *sections*—that is, *cuttings through*, exhibiting the order of relation among the several strata. The following section, for instance, exhibits strata at A in a *horizontal* position; at B in an *inclined* posi-

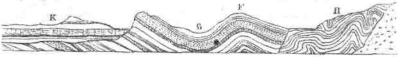


Horizontal and Inclined Stratification.

tion; at C in a highly inclined position, or *on edge*; and at D thrown or *tilted up*. The angle or slope at which a stratum inclines to the horizon is called its *dip*; and strata are accordingly said to dip at an angle of ten, twenty, or thirty degrees, as the case may be. When an inclined stratum comes to the surface, as at E, its edge is called the *outcrop*, and the line of outcrop is termed its *strike*. Thus we speak of the strike of a stratum being from east to west, and its dip to the north or south; in other words, the dip and strike are always at right angles to each other; hence the one being known, we can readily determine the course of the other. In the preceding illustration, the strata, though dipping at various angles, are all *plane* or straight; that is, the disturbing forces have merely broken up their original horizontality without producing any bendings, flexures, or contortions.

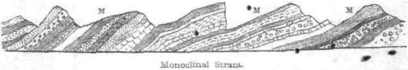
74. When strata dip in opposite directions from a ridge or line of elevation, like the roof of a house, as at F, the axis is said to be *anticlinal* (*anti*, opposite, and *clino*, I bend), and the strata are spoken of as forming an *anticline* or *saddleback*. On the other hand, when they dip towards a common line of depression, as at G, the axis is termed *synclinal* (*syn*, together), and the depression so formed is described as a *trough* or *basin*. When strata are bent and curved as at H, they are termed *contorted*; and frequent bendings are spoken of as *flexures*. Strata lying upon each other in parallel order are said to be *conformable*; but when one set overlies another set, and at a different angle, as at K, they are

termed *unconformable.* In the accompanying diagram, for example, the horizontal series K are unconformable to, or rest un-



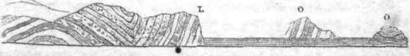
Unconformable, Bent, and Contorted Strata.

conformably on, the highly inclined series beneath them. When the same set of strata are bent into numerous troughs and ridges, or undulations, they are said (not very correctly) *to roll*; and when one portion of the same series is thrust or carried forward over another portion, it produces what is termed an *overlap*. In some instances an overlap is apt to be mistaken for unconformability, though the two are very different phenomena—the one being an overlie of a portion of the same beds produced by fracture and disturbance, the other an overlie produced by the deposition of a newer set of strata over the outcrops of an upturned one of earlier date. Occasionally the strata of a district, though lying at different angles, may all slope in the same way, and in such a case they are said to be *monoclinal* (*monos*, one and the same), or dipping in one main direction, as at M M M.



Monoclinal Strata.

75. When strata terminate abruptly in a bold bluff edge, they are said to form an *escarpment* (Fr. *escarpé*, steep), as at L; and such escarpments may either be the sides of hills, sea or river cliffs, or precipitous heights now far removed from the influence of water. Patches or masses of strata detached from the main body of the formation to which they belong are termed *outliers*, as at O O; and such outliers are often widely separated from

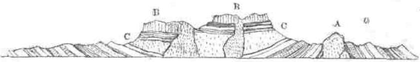


Escarpment—Outliers.

their original connection. In all cases of this kind, whether the outlier be an island detached from the parent continent, or an isolated mound in a valley, its connection is traced and confirmed either by the mineral similarity and succession of its strata, or

by the identity of its fossils with those contained in the main formation.

76. Rocks of igneous origin present themselves in the crust of the earth, either as *disrupting*, *interstratified*, or *overlying* masses. Thus, when igneous matter forces its way through the stratified rocks, and fills up the rents and fissures, it is termed disrupting, as at A; when, having passed through the strata, it spreads over their surface in sheet-like masses, as at B B, it is then said to be overlying; and when these discharges have taken place at the bottom of the sea, and have been in turn covered over by new deposits of sediment, they then appear as interstratified with the true sedimentary rocks, as at C C. Occasionally the interstratified

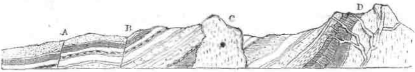


Overlying, Interstratified, and Disrupting Masses.

matter appears to have been ejected in the state of dust and ashes, and to have subsided as sediment in the ocean, there to be covered up by true aqueous debris; but in such cases an examination of the particles of the rock will generally determine its igneous origin. In true aqueous rocks the component particles are all more or less water-worn and rounded; in these igneous precipitates, the particles are sharp and angular, and in many instances their crystallographic forms are abundantly apparent. Further, true aqueous clays and muds are all less or more plastic; whereas volcanic ash and dust feel harsh to the finger, and have lost their *plasticity*, or property of being worked into a tenacious paste. On the other hand, where volcanic dust and mud have mingled themselves with the sedimentary matter of the ocean, and been subsequently consolidated into strata, it is often impossible to distinguish between such compounds and rocks of true aqueous origin; and for all practical purposes they may be regarded as ordinary sedimentary rocks.

77. The fissures and fractures produced in the rocky crust by volcanic agency are known by such terms as *faults*, *slips*, *hitches*, &c.; and when filled up by injections or infiltrations of mineral matter, they are spoken of as *dykes*, *lodes*, *veins*, &c. In the annexed diagram, A represents a simple slip or hitch where one portion of the strata appears to have slipped down, while another portion has been hitched up; B represents a fault, where the strata are not only displaced, but thrown up at different angles; C a dyke, where the fissure has been filled with igneous matter,

in the form of a dyke or wall; and D a suite of lodes or veins passing partly through unstratified and partly through stratified



Slip, Fault, Dyke, and Veins.

rocks. All such displacements or disturbances by which the strata are fractured or thrown out of their original position are known by the general term *dislocations;* and there is scarcely a square mile of the solid crust which does not bear abundant evidence of the application of disturbing forces. Indeed, it is impossible that upheavals or submergences of any portion of the earth's crust can take place without causing fractures and dislocations; and just in the manner and direction in which the volcanic force exerts itself, so will these dislocations be few or numerous, simple or complicated. As we shall have occasion to advert to the special aspects of these phenomena when we treat of the Practical Applications of the science, the student at this stage need only remember that the tendency of every earthquake and volcano is to rend and shiver the solid strata; that where the shock is unaccompanied by discharges of igneous matter, the fissures will simply be slips and faults; that where it is accompanied by igneous discharges, the molten matter will force its way through, and fill up the fissures, producing dykes; and that where the rents are subsequently filled up by infiltrations of mineral and metallic matter, the result will be lodes and veins.

78. To ascertain the dip and strike of strata, the lines of faults and dislocations, the direction of veins, and the like, the observer must carry along with him a pocket-compass and clinometer. In fact, without these simple instruments he cannot unravel the arrangement and relations of the strata in any district of country, however limited; and no satisfactory knowledge of superposition can be arrived at without correct and absolute sections. Thus the compass will readily indicate the bearings of faults and dislocations, the strike of strata, the direction of the dip, and other similar relations; and by ascertaining these facts at several points in any district, the relations of the intermediate portions which may be obscured by superficial coverings can be pretty accurately determined. Again, by the clinometer (*clino*, I slope, and *metron*, a measure)—which may form the frame-

work of the compass, and may consist of a square and plummet, or of a spirit-level and movable arm with a graduated radius—he can ascertain the angle of dip at any one point, and so determine the various upthrows and downthrows, the depressions, elevations, and convolutions to which the district under survey has been subjected. (See CHAP. XX.) If, for example, in travelling across a country, he finds the rocks at a certain point, A, dipping to the south, and after proceeding a few hundred yards he finds them at B dipping to the north, he may safely conclude that the space between forms a trough or basin. Again, if travelling southwards in the same direction he finds the strata

at C now dipping to the south, he may be certain that the space between B and C is occupied by an anticlinal axis or saddleback. Still going southwards, if he finds in some quarry, as at D, the strata continuing their southward dip, but at an angle of 60° instead of 20°, as at C, then he may be pretty sure dislocation has taken place, and would be justified in indicating the same on his map or section. Such a line of examination forms what is called *a line of section;* and a vertical section of the strata passed over might be represented as follows:—

It is by such processes (explained at length in another section) that the geological survey of a district is executed; the various formations being indicated by different colours; the strike of strata indicated by dark lines; the dip by arrows; and the internal arrangement and superposition by sections taken along such lines as the surveyor thinks best calculated to illustrate the peculiar structure of the country.

NOTE, RECAPITULATORY AND EXPLANATORY.

79. The object of the foregoing chapter has been to point out the arrangement and relations of the materials constituting the crust of the globe. The general tendency of aqueous action, wherever it manifests itself, is to wear down the rocks of exposed localities, and to transport the debris or waste material to the lower level of lakes, estuaries, and seas—there to be spread out, with greater or less regularity, in layers or strata. The tendency of igneous action, on the other hand, is to counteract this degrading effect—to throw up masses of new rock-matter, to elevate the land, and to produce new irregularities of surface by fracture and dislocation of the crust. Ascribing similar results to similar causes, and reasoning from the recent to the more remote, we find the same sort of arrangement and relations subsisting among the older and deeper-seated rocks of the globe. Wherever a section of the crust has been exposed, whether in natural cliffs and ravines, or in artificial quarries and mines, the rocks are found to be arranged either in layers or in indeterminate masses. Those arranged in layers have been evidently formed by the agency of water—those in shapeless masses by the agency of fire. Referring to their origin, the one set are termed the stratified, aqueous, or sedimentary—the other the unstratified, igneous, or volcanic. As a natural consequence of their formation, the igneous rocks break through, displace, and derange the original horizontal strata, which now appear inclined at various angles, fractured and contorted. The positions of the stratified rocks are indicated by such terms as plane, inclined, on edge, anticlinal, synclinal, bent, and contorted. Their dip or inclination is measured in reference to the horizon; their strike or line of outcrop is traced along the surface. The positions of the igneous rocks in reference to the stratified are spoken of as disrupting, overlying, and interstratified; and the fractures or rents caused by volcanic convulsion, as fissures, faults, dykes, and veins.

80. It is necessary to have a thorough comprehension of these terms, and the phenomena to which they are applied, before the student can hope to unravel the problems of geology. They occur in every description he will read; and he cannot make his own observations intelligible to others unless through the medium of the language peculiar to his science. As will hereafter be seen (CHAP. XX.), when treating of practical surveys, the ascertaining of the correct dip and strike of strata, and the direction of faults, dykes, and veins, is a matter of prime importance; and the student

should, therefore, early accustom himself to the use of the compass and clinometer—entering into his note-book sections and sketch-maps of every locality he examines. In using the compass, he should be careful, in every instance, to make allowance for the variation of the needle—laying down his bearings by the true meridian rather than by the magnetic, which cannot be so readily compared and harmonised with the results of common observation. As to the clinometer, he should aim chiefly at taking the general dip of the strata in question, and endeavour always to obtain as long a surface as possible whereon to apply the edge of his instrument. For this purpose his cane or hammer-shaft laid along the slope of a stratum will afford a more accurate line of dip than can be obtained by the short edge of the clinometer on any two or three inches of the stratum itself.

81. In noting the purely physical arrangement of the materials composing the rocky crust—that is, the relative positions of the stratified and unstratified masses—the student cannot avail himself of more accessible book-guides than the *Geological Observer* of De La Beche, and the prettily illustrated *Physical Geology* of Mr Beete Jukes. The latter work, illustrated by the pencil of M. Du Noyer, exhibits very faithfully the more important aspects of the various rock-relations, and will serve as a model to the young geologist, who should early accustom himself to the use of his pencil and sketch-book.

V.

COMPOSITION AND CHARACTERISTICS OF THE PRINCIPAL ROCKS AND ROCK-MASSES.

82. In the preceding chapter it has been stated that the crust of the earth is composed of stratified and unstratified rocks—the former the results of sediment in water, the latter the products of igneous fusion. It was also shown how the stratified rocks were broken up, displaced, and thrown out of their original horizontality by volcanic action; and how the igneous rocks were consequently intermingled with them in the form of disrupting, interstratified, and overlying masses. The relations of these two great classes of rocks to one another, and the technicalities employed to describe these relations, having been mastered by the student, he has next to acquaint himself with the structure, external characteristics, and composition of the principal rock-masses, that he may be enabled to comprehend their origin and mode of formation. The terms employed to describe these characteristics may be regarded as the language of his science—a language somewhat peculiar, but by no means difficult of attainment.

Structure and Texture of Rocks.

83. The *structure* of a rock refers to the manner in which it is piled up or aggregated in the mass; its *texture*, on the other hand, refers to the manner in which its individual particles are internally arranged. The former relates more especially to external aspects; the latter to internal constitution. On examining the face of a granite quarry, for instance, we find the rock arranged in large tabular or square-like masses—this is its structure; on breaking one of these blocks we find it hard, close-grained, and crystalline—this is its texture. The terms employed to designate the external structure are not very numerous, and their meaning

is familiar and obvious. Thus, speaking of stratified rocks, geologists employ the terms *stratum* and *bed* when the deposit is of considerable thickness; *layer* or *band* when it is thin and holds a subordinate place among the other beds; and *seam* when a rock of a peculiar character occurs at intervals among a series of strata. The miner, for example, speaks of a *seam of coal* occurring among strata of clay and sandstone, and of a *band* of ironstone occurring in a bed of shale. Though the terms *bed* and *seam* are thus loosely used by many geologists as synonymous with layer and stratum, bed ought to be applied only to the surface junction of two different strata, and seam to the line of separation between them. Thus, the upper surface of a stratum may be smooth, or it may be rough and irregular, and the under surface of the stratum laid above it must partake of this smoothness or this irregularity: this is *bedding;* the line that marks this separation between two strata is the *seam.* The term *post* is frequently applied to express a thick, uniform-grained stratum of sandstone; and *faikes,* a thin-bedded shaly sandstone of irregular composition; but the use of all local designations should be scrupulously avoided as long as we have general and well-understood terms capable of expressing the same thing.

84. When certain kinds of strata are capable of being split up into thin plates or leaves, they are said to be *laminated, flaggy, fissile,* and *shaly.* For instance, many sandstones and limestones show distinctly the layers of successive deposit, often as many as twenty of these laminæ in a single inch of thickness, and such are said to be *laminated;* others again, as the sandstones used in paving, are termed *flags* and *flagstones,* as splitting up in thicker layers; while any rock capable of being split up, whether in the line of bedding or otherwise, is said to be *fissile.* Clays and clayey beds, in their ordinary state, are soft and plastic; when consolidated, and having a tendency to split in the direction of their bedding, they are said to be *shales* or *shaly.* The terms *schist* and *schistose* (from the Greek *schisma,* a splitting or division) are properly applied to fissile rocks of crystalline texture, like gneiss and mica-schist, which have an irregularly laminated texture; while *slate* and *slaty* should be restricted to rocks which, like roofing-slate, split up regularly, and this in lines generally transverse to those of stratification. The terms *foliation* and *foliated* (often used when treating of schists and slates) refer to that internal leaf-like texture (*folium,* a leaf) which has often an extremely flexured aspect, as if the individual laminæ of the rock had been bent and folded over each other.

85. The structure that prevails among igneous rocks is less,

varied and more definite than that of the sedimentary, and appears in many instances to be the result of cooling, or crystallisation on a great scale. When they appear in columns, like the basalts of Staffa and the Giant's Causeway, they are said to be *columnar;* and when the columns are irregular, and not very distinct, they are termed *sub-columnar*. Certain greenstones and granites break up in large square-like blocks—a structure which is styled *tabular* or *cuboidal;* other rocks of the same classes break up in masses of no regular shape, and are consequently termed *massive* or *amorphous*. Many greenstones present a *spherical* or *globular* structure, the weathered cliffs of such a rock appearing like a huge accumulation of bombs and balls varying from a few inches to several feet in diameter. Such a structure, from its apparent aggregation round a common centre, is also termed *concretionary*, and generally *exfoliates*, on exposure to the weather, film after film, like the coats of an onion.

86. The internal texture of rocks is designated in like manner by terms expressive of the appearance they present when broken by the hammer. Thus, a rock is said to be *granular* when made up of distinct grains or particles, like granite ; *saccharoid* (like loaf-sugar) when the grains have a uniform crystalline aspect, as in many statuary marbles ; *porous* when full of pores or of open texture, like pumice ; *vesicular* or *cellular* when full of little cavities, like certain kinds of lava ; *fibrous* when composed of fibres or filaments, like asbestos ; and *acicular* (*acus*, a needle) or needle-shaped when the fibres are distinct and of moderate length, as in actynolite slate. *Conglomerates* are rocks composed of water-worn pebbles—in other words, consolidated gravel ; and *breccias*, or rocks of *brecciated* texture, are those in which the fragments are sharp and angular, from the Italian word *breccia*, a crumb or fragment. When a rock can be easily broken or crumbled down, it is said to be *friable ; compact* when of close and firm texture ; *earthy* when the texture is soft and dull ; *crystallised* when made up of distinctly formed crystals ; *crystalline* when sparkling and shining, but not composed of distinct crystals ; and *sub-crystalline* when the lustre is dull and somewhat less apparent. *Hard* and *soft* are employed in geology as in everyday language, with this distinction, that a rock may be hard and yet easily broken (*brittle*) ; soft, and yet not yield readily to the hammer. To express this quality, the term *tough* is generally employed ; but these and other minute distinctions belong rather to mineralogy than to geology. Generally speaking, the harder rocks give a sharp, ringing sound under the hammer, while the softer give a dull and heavy one ; hence the expressive *pif, paf,*

pouf of the Caen quarrymen—pif signifying hard, paf softer, and pouf the softest of all.

Mineral and Chemical Composition of Rocks.

87. The composition of the rocks constituting the crust of the globe may be viewed in two ways—either chemically or mineralogically. To the chemist, every substance in nature appears as composed of certain primary elements; and of such elements about sixty have been discovered—some gaseous, some liquid, some solid, some metallic, and others non-metallic. In examining a piece of marble, for example, the chemist resolves it into carbonic acid and lime; or, more minutely, into oxygen, carbon, and a metallic element called calcium. It is enough for the mineralogist, on the other hand, to know that it is a limestone, and to describe it as pure or impure, as soft or compact, as earthy or crystalline. The geologist, again, regards more especially its position and mode of occurrence, with what rocks it is associated, what fossils are imbedded in it; and from these and other data endeavours to arrive at the conditions under which it was formed, and the aspect of the world at the time of its formation. In drawing such conclusions, he is greatly aided by the deductions of chemistry and mineralogy; hence the importance of these sciences to the practical geologist.

88. Although the minuter distinctions of minerals, and the crystals of which they are composed, belong more especially to the sub-science, Mineralogy, still, as the descriptions of geology become intelligible only in proportion to the precision of the language employed, the student should render himself familiar, by an examination of actual specimens, with the leading facts relating to the cleavage, fracture, hardness, lustre, colour, and other sensible properties of the most abundant simple minerals. This forms, as it were, his first step in mineralogy: the discrimination of the minerals themselves, and the compound rocks they produce, constitutes another and more difficult stage of his progress. When we strike a crystal of calcareous spar, for instance, we find it has a tendency to split in a certain fixed direction—this is its *cleavage;* and every mineral has a plane in which it splits more readily than in any other direction. When a rock or mineral is broken by the hammer, the surface of the fracture assumes a certain appearance, and such appearances are distinguished by the terms conchoidal or shell-like, even, uneven, smooth, splintery, hackly, &c.; these constitute the form of its *fracture.* The

hardness or tenacity of a mineral is estimated by a conventional scale of ten degrees, assuming talc to be the lowest in the scale, and diamond the highest. Thus:—

Talc,	1	Adularia felspar,	6
Rock-salt,	2	Rock-crystal,	7
Calc-spar,	3	Topaz,	8
Fluor-spar,	4	Corundum,	9
Apatite, or phosphate of lime,	5	Diamond,	10

If, for example, a mineral can be scratched by rock-crystal, but can in turn scratch felspar, it is evident its hardness lies between 6 and 7 of the scale, and may be represented by 6.3 or 6.8, just as it seems to approach felspar on the one side, or rock-crystal on the other. As to *tenacity*, it is closely allied to hardness, and is usually distinguished by such terms as tough, sectile or easily cut by the knife, brittle, flexible, and so forth. The property of *lustre* is likewise distinguished by the ordinary English terms, dull, glimmering, glistening, splendent or shining, metallic, vitreous or glassy, resinous, pearly, and the like—all very obvious in their meaning and application. Minerals, and the rocks which they compose, exhibit every shade of *colour;* and this property, though distinguished by the usual terms, black, red, green, grey, yellow, &c., with the innumerable shades between, is often an important one in mineral discrimination. Their *optical properties*, or power of transmitting and reflecting light, are also valuable characteristics, some being transparent, some simply translucent, and others opaque. As with these, so with other properties connected with *refraction*, *polarization of light*, with *electricity* and with their *specific gravities*, which are all useful distinguishing tests and characteristics to the geologist, as well as to the mineralogist.

89. In treating the simple minerals of which the great rock-masses are composed, the pure mineralogist has to consider many minute distinctions which have often no immediate bearing on the problems of geology. He has to attend, for instance, to minute differences in chemical composition, to modifications of crystallographic form, and generally to all the properties and characteristics described in the preceding paragraph. In doing so, he has to establish, provisionally it may be, many hundreds of genera and species; hence to a certain extent the complexity and imperfections of his nomenclature and classification. Of these minerals, however, not more than thirty or forty enter largely into the composition of the most prevalent rock-masses; and for all the ordinary purposes of geology, and especially for the requirements

of the beginner, a knowledge of these will be amply sufficient. A descriptive list is given at the close of this chapter, and he who can readily discriminate the rocks and minerals to which it refers, has already acquired no mean amount of mineralogical information. *Half a century ago, Geology was little more than an elaborate* and extended description of rocks and rock-relations, the successive aspects of World-History as unfolded by the remains of plants and animals in the different formations being almost unknown, and the higher problems of Life and its creational progress subordinated to ingenious but futile attempts to arrive at a "Theory of the Earth" from a consideration of its mere mineral constituents. Notwithstanding this grand mistake, the student must on no account learn to underrate the value of Mineralogy as a branch of geology. The more extensive his acquaintance with mineral species, the more accurate will be his geological deductions; and the presence or absence of certain mineral forms will often throw light on his investigations, when fossil and mechanical aids have failed to inform him.

90. Respecting the chemical composition of rocks, little need be said in an elementary treatise. As with the mineralogical, so with the chemical aspects of geology: although the chemist resolves all known substances into some sixty-three elements or primary ingredients, yet of these comparatively few enter largely into the composition of the crust. To be acquainted with these principal ingredients, their nature and properties, and the external character of their compounds, is nearly all the geologist requires. To him, a limestone is a product of fresh water, or of marine origin, according to the nature of its fossils; to the mineralogist it is a carbonate of lime, earthy, compact, or crystalline, as the case may be; and to the chemist it is a compound of calcium, carbon, and oxygen. Again, to the geologist, granite is an igneous rock, eruptive or disruptive, associated with rocks of every formation, or passing in veins through strata of different epochs. The mineralogist regards it as a compound of three simple minerals—quartz, felspar, and mica—in certain forms and modes of aggregation. The chemist now takes up these simple minerals, and resolves the quartz into silica, the felspar into silica, alumina, and potash, and the mica into silica, magnesia, potash, lime, and peroxide of iron; or, carrying out an ultimate analysis, he converts the silica into silicon and oxygen, the alumina into aluminium and oxygen, the potash into potassium and oxygen, the magnesia into magnesium and oxygen, the lime into calcium and oxygen, and the peroxide of iron into iron and oxygen. Re-

presented in a tabular form, these geological, mineralogical, and chemical aspects of granite appear as under:—

Granite,	Quartz,	Silica,	Silicon. Oxygen.
	Felspar,	Silica,	Silicon. Oxygen.
		Alumina,	Aluminium. Oxygen.
		Potash,	Potassium. Oxygen.
	Mica,	Silica,	Silicon. Oxygen.
		Magnesia,	Magnesium. Oxygen.
		Potash,	Potassium. Oxygen.
		Lime,	Calcium. Oxygen.
		Peroxide of Iron,	Iron. Oxygen.

Geological, mineralogical, and chemical considerations are thus inseparably interwoven; and hence the value of chemical knowledge in enabling the student to arrive at correct conclusions respecting the origin of many rocks and the subsequent changes they have undergone. For this purpose he does not require to spend years in the laboratory; it is enough if he can appreciate the conclusions of the chemist and know how to apply them.

91. Chemistry, we have stated, has already resolved all objects in nature,—whether mineral, vegetable, or animal—solid, liquid, or aëriform,—into *sixty-three* elementary or ultimate substances. Of these only a few enter largely into the composition of the earth's crust; and of the others many are extremely rare, or only evolved from their natural unions by chemical analysis. In the following list the most important (geologically speaking) are printed in capitals, their characters being given as under the ordinary pressure and temperature of the atmosphere:—

Gases—HYDROGEN, OXYGEN, nitrogen, CHLORINE, and FLUORINE.

Non-Metallic Liquids and Solids—Bromine, iodine, SULPHUR, PHOSPHORUS, selenium, CARBON, boron, SILICON.

Metals being the bases of the Earths and Alkalies—POTASSIUM, SODIUM, lithium; barium, strontium, CALCIUM; MAGNESIUM, ALUMINIUM, thorium, glucinium, zirconium, yttrium.

The Metals—MANGANESE, ZINC, IRON, TIN, cadmium, COBALT, NICKEL; ARSENIC, CHROMIUM, vanadium, molybdenum, tungsten, columbium, ANTIMONY, uranium, cerium, BISMUTH, titanium, tellurium, COPPER, LEAD; MERCURY, SILVER, GOLD, PLATINUM, palladium, rhodium, osmium, iridium, ruthenium; (and the following, of which little is yet determined), erbium, terbium, didymium, lanthanium, niobium, norium, ilmenium, pelopium.

Such are the "elements" or "simple substances" of the chemist; and though this is not the place to enter into details, we cannot leave the subject without advising the student to render himself practically familiar with the nature and properties of the more abundant elements. A few simple tests, such as are indicated in any manual of chemistry, are not of difficult application; and after a little practice of this kind the eye learns to detect at first sight the presence of most of the elements in their ordinary combinations.

Most abundant Rocks and Minerals.

92. Having now learned something of the structure and texture of rocks, and of their mineral and chemical composition, it is necessary to be able to distinguish one from another, and to describe it by the name by which it is usually known. For this purpose there is nothing better than frequent examination of specimens correctly labelled and arranged in a cabinet or museum. One day well spent in this manner is worth a month's reading of written descriptions; although such lists as the following are not without their uses in assisting the beginner to draw distinctions, and fix on his memory the meaning of the nomenclature adopted. The arrangement is neither strictly mineral nor chemical, but is founded on such obvious distinctions as must meet the eye of the most casual observer. Thus, in every region we find a great proportion of the rock-substances composed of sand or of fragments more or less approaching the state of sand (*arenaceous*); another notable proportion are clayey or *argillaceous;* a third limy or *calcareous;* a fourth more or less coaly (*carbonaceous*); a fifth always composed of mineral crystals less or more distinct (*crystalline*); a considerable class are *saline* or salt-like; and others, again, are decidedly *metallic* in their aspect, as the ores of the metals. Distinctions such as these are natural and obvious; and any classification founded upon them will be easily mastered by the student at this stage of his progress:—

(*Arenaceous and Fragmentary Compounds.*)

Sand is an aggregation of water-worn particles, derived from pre-existing rocks and other mineral substances. It is generally composed of quartz grains (quartz being one of the hardest of simple minerals, and longest resisting the processes of attrition); but it may also consist of the particles of shells, corals, &c.; hence such terms as shell-sand, coral-sand, and the like.

Gravel is the term applied to the water-worn fragments of rocks when the particles or pebbles vary from the size of a pea to that of a hen's egg. It is generally composed of the fragments of the harder and more siliceous rocks.

Shingle is the geological term for water-worn rock-fragments larger and less rounded than those of gravel. Shingle-beaches are common on the more exposed portions of our sea-coasts.

Rubble is a convenient and expressive term, applicable to accumulations of angular rock-fragments indiscriminately thrown together, and such as usually arise from river-freshets or ice-drift, or are piled at the bases of wasting cliffs and precipices.

Boulder is the term employed to denote larger water-worn blocks of stone found on the soil or amid the surface material. They are often detached and of great size, weighing many tons in weight.

Sandstone is simply consolidated sand, the particles having been compacted by pressure, or being held together by lime, clay, oxide of iron, or some other cementing material.

Grit is the term applied to a sand rock when the particles are hard and angular, that is, "sharper" than in ordinary sandstones; hence their value as millstone-grits, grindstone-grits, &c.

Conglomerates are aggregations of gravel and pebbles of all sizes—in other words, consolidated gravel. They are sometimes known as *puddingstones*, from the fanciful resemblance of their pebbles to the fruit in a plum-pudding.

Breccias (from an Italian word signifying a crumb or fragment) are rocks composed of an agglutination of angular fragments. A breccia, or brecciated rock, differs from a conglomerate in having its component fragments angular and irregular, whereas the pebbles of the latter are all rounded and water-worn.

(*Argillaceous Compounds.*)

Mud is the familiar as well as technical term applied to the fine impalpable matter worn and borne down by water, and deposited at the bottoms of seas, lakes, and pools. It is thus composed of the finely comminuted debris of mineral, vegetable, and animal matter.

Clay is also a fine impalpable sediment from water, but consists wholly, or almost so, of aluminous and siliceous particles. It is usually tough and plastic, and differs from mud in this respect as well as in the absence of vegetable and animal matter.

Silt is a geological term for the miscellaneous matter deposited in lakes, estuaries, bays, and other still waters. Silt may thus consist of intermingled mud, clay, and sand, or of distinct layers of these.

Shale is merely consolidated mud assuming a structure less or more laminated. This laminated or shaly structure distinguishes it from beds of clay and marl.

Mudstone is a convenient term recently introduced to designate an earthy, clayey rock, void of shaly lamination; evidently consolidated mud.

Slate is often applied indiscriminately to all hard laminated argillaceous rocks that can be readily split up. The term, however, should be restricted to those in which the clayey particles predominate, and the consolidation is so perfect that the mass assumes a semi-crystalline aspect like ordinary roofing-slate.

Claystone is the term usually applied, but not very happily, to an indurated massive argillaceous rock of igneous origin. Rocks containing a notable proportion of clay emit, when breathed on, a peculiar and distinctive odour (argillaceous odour), which is easily recognised.

(*Calcareous Compounds.*)

Limestone is the general term for all rocks, the basis of which is carbonate of lime; that is, lime in chemical union with carbonic acid. As limestone is dissolved with violent effervescence by sulphuric and muriatic acids, its presence may be easily detected by a drop of these liquids.

Marble is an architectural rather than a geological term, and is applied to the compact crystalline and mottled varieties of limestone used for statuary and ornamental purposes. Limestone, on the other hand, is the ordinary term for the duller and less compact kinds used for mortar and in agriculture.

Chalk is a familiar as well as technical term for the softer and earthier-looking varieties of limestone.

Marl is a loose appellation for all friable compounds of lime and clay; called "clay-marls" or "marl-clays," as the one or other ingredient predominates. "Shell-marl" is the term applied to such varieties as contain abundant remains of fresh-water shells.

Gypsum is a sulphate of lime, which, when calcined, forms the well-known plaster-of-Paris. It occurs either massive, granular, or fibrous; when crystallised it is known by the name of *selenite*.

Magnesian Limestone.—Many limestones contain a small percentage of magnesia, but those only are entitled to the term which contain from twenty per cent and upwards.

Dolomite (after the geologist Dolomieu) is a granular or crystalline variety of magnesian limestone.

(*Carbonaceous and Bituminous.*)

Coal is a well-known substance, and may be briefly described as mineralised vegetable matter, containing less or more of earthy impurities. In burning, the organic or vegetable matter is consumed, and the earthy or inorganic matter is left behind as ashes. Coal occurs in many varieties, as *anthracite*, which is non-bituminous, and burns without smoke or flame, *caking coal, splint coal, cannel coal*, &c., which, on the other hand, are all less or more bituminous.

Jet is a compact variety of coal susceptible of a high polish, and on that account usually worked into personal ornaments.

Lignite (*lignum*, wood), also known as "brown coal," is a variety of recent formation, in which the woody structure is distinctly apparent.

Graphite or *Plumbago* (the substance of which writing-pencils are made) is almost pure carbon. Though familiarly called "black lead," it contains no lead whatever, but is simply carbon with a slight trace of iron and earthy impurities. The name graphite (*grapho*, I write) refers to its use; *plumbago* (*plumbum*, lead) refers to its appearance.

Bitumen is an inflammable mineral substance found either in a free or in a combined state. As free bitumen it occurs limpid as *naphtha*, liquid as *petroleum* or rock-oil, slaggy as *mineral pitch*, and solid as *asphalt*. It can be discharged from coals, coaly shales, and other substances, by the application of heat; hence these minerals are said to be "bituminous," or more properly "bituminiferous."

(*Simple Minerals and their Rock-Compounds.*)

Quartz, properly speaking, is pure silica; *rock-crystal* is the name given to pure transparent varieties; and coloured varieties are known as *amethyst*, *topaz*, &c. The crystal form of quartz is a six-sided prism terminating in a six-sided pyramid.

Quartz-rock is massive quartz of various colours, and occurs in veins or stratiform masses.

Quartzite is the term applied to the granular varieties, and to sandstones apparently reconverted by intense heat into quartz.

Jasper, Hornstone, Lydian stone, &c., are compact siliceous rocks of various colours, exhibiting smooth, glassy fractures.

Flint is impure nodules of silex, abundantly found in chalk strata, and apparently aggregated from silica in solution.

Chert is the name given to an admixture of flint and limestone, and occurs in concretions, nodules, and rock-masses.

Felspar, as chiefly composed of silica, alumina, and potash or soda, is a softer mineral than quartz. The softer crystals occurring in granite are of felspar; they can be scratched by the knife, when quartz resists it; and can also be known by the straight, glassy aspect of their cleavage.

Compact Felspar and *Felstone* are amorphous rocks of felspar, forming dykes and mountain masses.

Mica and *Mica-schist*.—The glistening and scaly crystals in granite are mica, so called from the Latin word *mico*, I glisten. Mica is a soft, sectile mineral, is readily split into thin transparent plates, and is mainly composed of silica, potash, and magnesia. It forms the principal ingredient in a set of slaty rocks called *mica-schists*; and it occurs in minute scales in many sandstones, giving to them a silvery appearance.

Hornblende, so named from its horny, glistening fracture (*blenden*, to dazzle), is a dark-green or black mineral found in granites and greenstones. It also occurs massive as *hornblende-rock*; or slaty as *hornblende-schist*.

Augite — Hypersthene. — These are blackish-green, greenish-black, or greenish-grey minerals nearly allied to hornblende. They occur largely in all igneous rocks, and will best be distinguished by examination of actual specimens. They differ slightly in mineral composition and in form; hence regarded as distinct minerals.

Actynolite (*actin*, a thorn), another mineral very closely allied to hornblende, and deriving its name from the thorn-like shape of its crystals. It occurs massive as *actynolite-rock*, and thickly dispersed in some slates—*actynolite-slate*.

Asbestos or *Amianthus*, so well known from its fibrous texture, may be regarded as a variety of actynolite. It occurs in various modes of aggregation, and thence known as "mountain-wood," "mountain-cork," "mountain-leather," &c.

Chlorite—Chlorite-schist.—Chlorite (from the Greek word *chloros*, greenish-yellow) is a mineral of a greenish hue, and generally of a foliated texture, in which condition it forms the principal ingredient in the greenish rock called *chlorite-slate* or *chlorite-schist*. Chlorite, in chemical composition, is closely allied to mica.

Talc—Talc-schist.—A whitish-green magnesian mineral, closely allied to and resembling mica. It is transparent in thin plates, but is generally massive, sectile, soft, and non-elastic. It enters largely into many of the earlier schists, known as talc-schists and talcose slates.

Steatite—Soapstone—Potstone.—All rocks containing steatite, which may be regarded as a variety of talc, have a greasy or soapy feel; hence the name from *stear*, fat or grease. On this account some varieties have been termed *soapstones*; and others, from their sectility and power of resisting heat, are known as *potstones*.

Serpentine, so called from its varying green, blackish-green, and purplish colours (like the back of a serpent), is one of the magnesian rocks occurring largely in many primitive districts.

(*Igneous Crystalline Rocks.*)

Granite—Syenite.—Ordinary granite is a granular compound of quartz, felspar, and mica, varying in colour according to the presence of iron, &c., in one or other of the component minerals. When mica is wanting, and its place is supplied by hornblende, the rock is called *syenite*, from Syene in Upper Egypt, where it was early quarried. There are several varieties of granite arising from such interchanges of minerals, but these will be noticed when we come to treat of the granites as a geological group.

Basalt—Greenstone—Clinkstone.—These are rocks of igneous origin, and are chiefly distinguished by their hardness, compactness, and colour. Ba-

salt is a close-grained, dark-coloured rock, often occurring in columns more or less regular; greenstone is not so close in the grain, is lighter in colour, and occurs either in tabular or amorphous masses; and clinkstone (so called from the metallic ringing sound it emits when struck by the hammer) is only a compact, fine-grained, greyish variety of basalt. Augite, hornblende, and felspar, are the chief ingredients in basalts and greenstones.

Trap-rock (from the Swedish *trappa*, a stair, and so called from the step-like aspect it gives to the hills composed of it) is a name which includes a great variety of igneous rocks, the general characters of which are easily recognised in the field. Basalt and greenstone may be included under the term *trap*; but the word is more frequently applied to the looser and less crystallised masses known as *trap-tuff*, *wackè*, *amygdaloid*, &c.

Trachyte—Trachytic Greenstone.—Trachyte is a granular volcanic rock of a greyish colour, and so called from its harsh feel (*trachys*, rough); and trachytic greenstone is a rough-grained, felspathic variety resembling greenstone.

Lava—Pumice—Scoriæ.—Lava is the name for all molten discharges from recent volcanoes; pumice is the light cellular froth or scum of such discharges; and scoriæ comprehends all the loose cindery or slaggy matter.

Porphyry—Porphyritic.—The term porphyry (Greek *porphyra*, purple) was originally applied to a reddish rock found in Upper Egypt, and used by the ancients in ornamental architecture. The word is now employed in a technical sense to denote all rocks (whatever their colour) that contain imbedded crystals distinct from their main mass. We have thus felspar-porphyry, porphyritic granite, and porphyritic greenstone.

(*Saline, &c.*)

Common Salt (chloride of sodium) is too well known to require description. It is found in thick incrustations on many sea-coasts, and in the sites of dried-up lakes. It occurs abundantly in the solid crust as *rock-salt*; and is held in solution by all sea-water and brine-springs.

Nitrates of Soda and Potash occur as incrustations and efflorescences in [illegible] plains, marshes, and lakes in hot countries. These salts are known as *natron*, *trona*, &c.

Alum (sulphate of alumina and potash), though chiefly extracted from certain shales and schists, is also found in nature in the saline or crystallised state.

Borax (soda and boracic acid) is another saline product abundantly discharged by the thermal springs of some volcanic districts.

Sulphur is found massive and in crystals in almost all volcanic districts. It is also found largely in chemical combination with many of the earths and metals.

(*Metallic.*)

The Metals are either found *native*—that is, in a pure state—or combined with mineral matter in the state of *ores*. Gold and silver are often found native in pellets, nuggets, and thread-like branches; the other metals are chiefly found as *ores*. Lead, for instance, is found in sparry veins as a sulphuret (*galena*), carbonate, phosphate, &c.; copper, zinc, tin, and manganese, are found generally in a similar way; iron is found either in veins and masses as a peroxide, &c., or in strata as a carbonate, like the clay-ironstones and black-bands of our coal-fields.

NOTE, RECAPITULATORY AND EXPLANATORY.

93. In the preceding chapter we have endeavoured to explain the composition and characteristics of the principal rock-masses; that is, the modes in which they are piled up or aggregated, and the mineral elements which enter into their constitution. A knowledge of such characteristics is indispensable to the comprehension of their origin and formation; and the terms employed to express these characteristics must be mastered before we can hope to understand, or make ourselves understood by, our fellow-geologists. The structure and texture of rocks, whether of aqueous or of igneous origin, are distinguished by a variety of terms expressive of their appearance as they occur in the crust, or when broken up by the hammer. Thus, the layers of the stratified rocks are spoken of as strata, beds, seams, bands, flags, slates, and schists, according to their thickness; while the unstratified occur as columnar, subcolumnar, tabular, massive, and amorphous. As to the texture or internal structure of rocks, it is extremely varied, and is defined by such obvious terms as hard, compact, crystalline, saccharoid, granular, porous, vesicular, and the like. The composition of rocks, we have seen, may be viewed either in a chemical or mineralogical light; but, in whatever light they are viewed, it is enough for the beginner in geology to be able to distinguish, at sight, such ordinary rocks as sandstone, conglomerate, shale, clay-slate, limestone, chalk, gypsum, rock-salt, coal, quartz, mica, felspar, granite, gneiss, greenstone, basalt, trap-tuff, lava, and a few of the ores of the more abundant metals.

94. To be able to distinguish the ordinary rocks which occur in our own cliffs and quarries is enough, we have said, for the purposes of the beginner; but he who has made some progress in the science will at once see the importance of more minute mineral and chemical distinctions. The presence of some peculiar mineral, for instance, may often help us to identify strata very widely separated, or to trace some ice-drifted boulder to its parent cliff when no other aid is available. The prevalence of some peculiar pebble in a conglomerate—and this peculiarity depending, it may be, on the presence of some accidental mineral—may lead us to infer with certainty whether such conglomerate was derived from the waste of rocks existing in the region where it occurs, or had been borne from remote and unknown continents. And as it happens that all the crystalline rocks derive their names and distinctions from their mineral composition, it must be evident that the geological attainments of him who knows little of mineralogy

will be limited and uncertain compared with those of the practised mineralogist.

95. Again, since every mineral has its own chemical composition, and the combinations and decompositions of chemical elements are governed by fixed and known laws, the student who has a knowledge of these laws will be better able to account for phenomena, and to say what is possible or impossible, than he who has no such knowledge to guide him. To take a few obvious examples: *crystals of gypsum (selenite) occur abundantly in certain* tertiary clays, and are forming, it may be, at the present moment. How is this? These clays, it is found on examination, contain carbonate of lime, and sulphuret of iron round some organic nucleus; and through the percolation of carbonated waters a decomposition of these ingredients takes place, sulphuric acid is generated, and, uniting with the lime, forms a new compound, gypsum or sulphate of lime. Again, we know that silica is held in solution by many thermal waters, like the geysers of Iceland; *and, knowing this fact, we can account for the presence of flints* in chalk, of quartz-veins in many rocks, and of other similar phenomena, without having recourse to any impossible theory of animal or igneous agency. Quartz or silex by itself is a most *intractable and refractory substance; while, in combination with* a little potash or soda, it is readily fused, and, on cooling, forms a glass, slag, or granular rock, according to the rapidity or slowness with which it is cooled. Knowing the greater affinity that certain substances have for others, their degree of fusibility, their power of retaining and parting with heat, their mutual decompositions and reunions—in fact, knowing more or less their whole chemical relations, and the influence of physical conditions, such as pressure, &c., on these relations—we enter upon the investigation of geological problems with an unerring light for our guidance—a light without which many of these investigations would be impossible, and much of geology little better than ingenious guess-work.

96. *In following out his researches on the mineral and chemical* constitution of rocks—and, above all, learning to discriminate by external aspect—the student, as already hinted, cannot do better than examine with the eye and eye-glass the specimens in some well-arranged and properly labelled collection. There is always some external characteristic of fracture, cleavage, lustre, colour, hardness, and so forth, sufficiently persistent to guide the observer; and it is astonishing how readily and accurately an attentive eye learns to appreciate such distinctions. Where book assistance is wanted, M'Culloch's *Geological Classification of Rocks*,—a work

of some date, but of great practical value; Professor James Nicol's *Manual of Mineralogy*, which brings up to a recent date the synonyms and analyses of European mineralogists; and Professor Dana's *System of Mineralogy*, either in the abridged or extended form, will supply the inquiring student with all (and unfortunately with a great deal more than all) he is ever likely to require. Where the chemical actions and reactions that take place among rock-masses are more immediately concerned, the *Chemical, Physical, and Geological Researches* of Professor Bischof, will be found to render at once the most ample and available assistance.

VI.

CLASSIFICATION OF THE MATERIALS COMPOSING THE EARTH'S CRUST INTO SYSTEMS, GROUPS, AND SERIES.

97. To arrive at a knowledge of the past aspects and conditions of the globe, it is necessary to do something more than examine the mere mineral constituents of its masses. These of themselves tell little unless studied in connection with their fossils, their order of superposition, and other stratigraphical relations. It is by such an investigation that we are enabled to determine the relative ages of strata, to judge whether they were deposited in lakes, in estuaries, or in seas, and to say what kind of plants and animals flourished during the time of their formation. At the present day, the layers of mud, clay, sand, and gravel depositing in tropical estuaries and seas, will contain less or more the remains of plants and animals peculiar to the tropics; the deposits forming in temperate regions will contain, in like manner, the remains of plants and animals belonging to temperate climates; and should a time arrive when these layers are converted into solid strata, the fossilised plants and animals will become a certain index to the conditions of the region at the time of their entombment. As with deposits now in progress, so with the strata constituting the solid crust: the lowest must have been formed first; the series beneath must be older than that above it; strata abounding in shells, corals, and other marine remains, must have been deposited in the sea, while those containing fresh-water plants and animals give evidence of a lacustrine or estuary origin; igneous rocks, which displace and break through any set of strata, must be more recent than these strata; and if another set of strata overlie these igneous rocks, then must they have been deposited in water at a period subsequent to the igneous eruptions. These and similar propositions are so apparent, that the student can have little difficulty in comprehending the principles upon which geologists have proceeded in classifying the rock-formations of the globe.

98. The principal guides to geological classification are, therefore, *order of superposition among the strata, their mineral composition, and the nature of their imbedded fossils.* The most superficial observer must have noticed the different aspects of the rocks in different districts, and a little closer inspection will enable him to detect that one set lies always beneath another set, and that while certain shells and corals are found in the lower series, the upper series may contain only the remains of terrestrial vegetation. In other words, he will find sandstones, conglomerates, shales, and limestones, each pointing to different agencies and conditions of formation. He will find certain limestones or sandstones always maintaining a fixed position in relation to the other strata; and he will, in all probability, discover that while the limestones are studded with shells and fragments of corals, the shales and sandstones contain only the impressions of leaves, branches, and trunks of trees. It is by this kind of testimony—viz., superposition, mineral character, and fossil contents—that the geologist is enabled to decipher the history of the earth's crust; and, as the student will afterwards find, every peculiarity of texture and structure, every lamina of stratum, every ripple-mark and impression on its surface, tells some important tale of the past; while a solitary tooth, the fragment of a bone, a microscopic shell, or the drifted frond of a fern—ay, even the minutest spine and punctures on these—will enable him to decide with certainty as to conditions of sea and land, estuary or ocean-bed, a cold boreal climate, or one of tropical temperature.

99. Thus, in sinking a shaft in the neighbourhood of London, we would pass through thick beds of soft plastic clay, layers of sand, and strata of water-worn flint gravel; at Cambridge we would pass through strata of chalk; in the east of Yorkshire, through strata of fine-grained sandstones, and soft yellowish limestones called oolite; at Newcastle, through strata of shale, coal, and coarse-grained sandstones; in Forfarshire, through strata of red and greyish sandstones and conglomerates; while on the flanks of the Grampians, we would pass through beds of roofing-slate and hard crystalline schists. On a minuter inspection of these strata, we would find that one series lay beneath, or was older than another series; that the chalk, for example, lay beneath the clays of London; that the yellow limestones of York lay beneath the chalk; that the coals of Newcastle were deeper seated than the oolites of York; and the red sandstones of Forfar still deeper than the coal-bearing strata. Further, when we began to examine the fossil contents of these different strata, we should find each set characterised by peculiar plants and animals

—some containing marine shells and corals, some the remains of large reptiles and fishes, and others replete with the debris of terrestrial vegetation. By these methods we would soon be enabled to identify the chalk strata of Cambridge with those of Kent, the oolites of York with those of Bath, the coal-measures of Newcastle with those near Glasgow, and the slates of the Scottish Highlands with those of Cumberland and Wales. As with the rocks of Britain, so with those of every country investigated by geologists; and thus they have been enabled to arrive at a pretty accurate classification of the stratified rocks, both in point of time and mineral character.

Progress of Geological Classification.

100. Without entering minutely into the history or progressive steps of this classification, it is necessary to draw attention to several of its features, as these are still retained in geological nomenclature, and more or less influence our ideas of succession and arrangement. The earlier history of geology is more curious than instructive, for it was long before correct notions were arrived at, either of the vast antiquity of our earth, of the numerous phases its superficial crust had assumed, or of the successive races of plants and animals that had peopled its land and waters. The first permanent division of rock-masses was that made by Leibnitz in 1680, when he divided them into *stratified* and *unstratified* — the former the products of deposition in water, the latter the results of igneous fusion. A little before his time (1669) Steno had introduced the terms *primary* and *secondary*—the former embracing all rocks void of fossil remains, and contemporaneous with the creation of the earth itself; the latter, those that were fossiliferous and formed since that period. This idea was taken up by Lister, Hooke, Fuschel, and others, and various subdivisions proposed—partly from the composition of the secondary rocks themselves, and partly from the different fossils they contained. Little or nothing of these subdivisions are now retained; and perhaps the most definite was that of Lehmann (1756), who added a third grand division to those proposed by Steno, thus—

LOCAL—Partial and local in different regions.
SECONDARY—General, and containing fossils different from plants and animals now existing.
PRIMARY—Universal, and devoid of fossils.

The next important advance was that made by Werner, who,

finding in many of the so-called primitive rocks distinct evidences of a stratified or mechanical origin, as well as traces of fossils, proposed to subdivide them into *primary* and *transition*. This arrangement, as well as the more exact ideas he attached to the terms secondary and local, were at once adopted by his contemporaries, and continue to influence, more or less, our schemes of classification up to the present day. His scheme, briefly viewed, may be tabulated as follows :—

ALLUVIAL—Local and superficial accumulations of sand, clay, gravel, peat-moss, and the like.

FLOETZ (flat-lying)—*Secondary* or fossiliferous strata of sandstone, limestone, gypsum, chalk, coal, &c.

TRANSITION—Transition limestone, greywackè, flinty slate, &c., partially fossiliferous.

PRIMARY—Of crystalline origin and devoid of organic remains.

Such was geological classification till about the beginning of the present century: nor were these views of arrangement arrived at without a great deal of controversy and opposition. It was then that the battles of opinion were fought between *Cosmogonists*, *Diluvialists*, and *Fossilists*—the first building up crude theories of the universe on a slender basis of facts; the second ascribing every phenomenon in the earth's crust to the operation of the Noachian deluge; while the last contended, on fossil evidence, for the long continuance of the agencies now productive of change on the face of the globe. During this time, also, the *Wernerians* or *Neptunists* contended strenuously for the aqueous origin of all the old rock-formations; while the *Huttonians* or *Vulcanists*, in opposition, advocated an igneous and eruptive origin for the traps, basalts, greenstones, and granites. These schools and controversies have long since passed away; and though it is sometimes said that every word on geology, previous to the present century, might be obliterated without causing much inconvenience to its present cultivators, still the language of the science is so impregnated with technicalities, as well as in some measure with modes of thought derived from these early schools, that there can be no intelligent progress without some acquaintance with their history.

101. About the beginning of the present century William Smith, "the father of English geology," some of the founders of the London Geological Society (1809), Saussure, Cuvier, and others, began to proceed upon more philosophical methods. Group after group of strata was examined, sectionised, and mapped, not according to mineral composition alone, but according to order of superposition, and, above all, according to

their distinctive fossil contents. The motto and maxim was then to examine and compare, collect and describe facts, and to accept all hypotheses and generalisations as mere provisional aids and expedients. Proceeding upon this method, new subdivisions and arrangements were proposed by several investigators; but few met with acceptance, and the following modification of Werner's scheme continued for many years to give direction and consistency to the researches of modern geology:—

FORMATIONS.

RECENT.—All superficial accumulations, as sand, gravel, silt, marl, peat-moss, coral-reefs, &c. *Contain the remains of existing plants and animals only partially fossilised.*

TERTIARY.—Local and limited deposits of regular strata occurring above the chalk. *Contain the remains of plants and animals not differing widely in character from those now existing.*

SECONDARY.—Embracing all the strata known as chalk, oolite, lias, coal-measures, mountain limestone, and old red sandstone. *Contain fossil plants and animals of species totally different from those now existing.*

TRANSITION.—Strata of slaty and siliceous sandstones, known as "greywackè," calcareous shales, and limestones. *Contain few or no fossil plants, and the remains of no higher animals than crustacea, shell-fish, and zoophytes.*

PRIMARY.—All slaty and crystalline strata—as roofing-slate, mica-schist, and gneiss, very hard and compact, and totally destitute of organic remains.

Life-Systems of Modern Geologists.

102. By a more extensive examination of the strata in different countries, and especially by a more minute investigation of their fossil contents, these formations of the earlier geologists have since been subdivided into systems, groups, and series. This new arrangement has been founded either on mineral or on fossil distinctions—such differences being sufficient to warrant the conclusion that each set of strata was formed during successive epochs, under different distributions of sea and land, and consequently under different conditions of climate and other modifying influences. The terms formation, system, group, &c., are somewhat loosely employed by geologists: but in the succeeding chapters we shall use the term *system* to signify any great assemblage of strata that have a number of mineral and fossil characters in common; the term *group*, to denote any portion of a system marked by a closer resemblance of mineral and fossil character; the term *series*, to designate any portion of a group which has some very marked character, either mineral or fossil; and so on with other subdivisions of the stratified formations. A system may thus comprehend several groups, a group several series, and

a series may have several distinct *stages* or *horizons* at which some peculiar forms of life appeared in greatest abundance. Proceeding upon this principle, the stratified rocks, from the superficial soil to the lowest known depth, may be subdivided into the following systems and groups :—

I. POST-TERTIARY SYSTEM, comprising all alluvial deposits, peat-mosses, coral-reefs, raised beaches, and other recent accumulations. *Remains of plants and animals belonging to species now existing, or but recently, and, for the most part, only locally extinct.*

II. TERTIARY SYSTEM, embracing the "Drift," and all the regularly stratified clays, marls, limestones, and lignites, above the Chalk; arranged into pleistocene, pliocene, miocene, and eocene groups. *Remains of plants and animals for the most part belonging to extinct species, but not differing widely from those now existing in the same geographical regions, save in the huger and perhaps more varied phases of mammalian life.*

III. CHALK or CRETACEOUS SYSTEM, embracing the chalk and greensand groups. *Remains of plants and animals chiefly marine, and belonging to species now extinct.*

IV. OOLITIC SYSTEM, comprising the wealden strata, the upper and lower oolite, and the lias. *Remains of plants and animals, belonging to genera most of which are now extinct, the more remarkable being huge reptilia, aquatic and terrestrial, and an exuberant exhibition of cephalopods in molluscan life.*

V. TRIASSIC SYSTEM, embracing the upper portion—saliferous marls, muschelkalk, and variegated sandstones—of what was formerly termed the "new red sandstone." *Remains of plants and animals more closely allied to those of the oolite system above, than to those of the carboniferous.*

VI. PERMIAN SYSTEM, embracing the lower portion—magnesian limestones and red sandstones—of what was formerly termed the "new red sandstone." *Remains of plants and animals very closely allied, and often identical with those of the carboniferous strata. At this stage we have, as yet, the first indications of bird and mammalian life.*

VII. CARBONIFEROUS SYSTEM, embracing the coal-measures, the mountain limestone, and the carboniferous slates. *Remains of plants and animals abundant—the distinguishing features being an exuberant endogenous vegetation in the coal-measures, and marine shells and zoophytes in the mountain limestone. As yet we have few insects, few reptiles, and no indication of birds or of mammals.*

VIII. DEVONIAN SYSTEM or OLD RED SANDSTONE, embracing the yellow sandstone, red conglomerate, and grey flagstone groups. *Remains of plants few and indistinct; of zoophytes, mollusca, crustacea, and fishes abundant, but as yet no undoubted traces of higher forms.*

IX. SILURIAN SYSTEM, embracing the upper and lower silurian groups, or the Ludlow, Wenlock, and Llandeilo series. *Remains of marine plants few and fragmentary; peculiar zoophytes, radiata, mollusca, and crustacea abundant in certain areas. Few fishes have yet been discovered, and these chiefly in the upper strata as developed near Ludlow in England.*

X. METAMORPHIC or NON-FOSSILIFEROUS SYSTEM, embracing the clay-slate, mica-schist, and gneiss groups. *All hard and crystalline rocks devoid of fossils.*

103. Such are the stratified rocks when arranged in systems and groups; and, so far as geologists have been enabled to discover, there is no deviation from this order of succession. It must not be supposed, however, that all these groups are found at any part of the crust, lying one above another like the coats of an onion; on the contrary, only one or two of the groups may be developed, and these very scantily, and not in immediate succession. All that is meant by *order of succession* among the stratified rocks is, that wherever two or more systems come together, they are never found out of place; that is, the chalk is never found beneath the oolite, oolite beneath the coal, or coal beneath the old red sandstone. In Fifeshire, for example, the carboniferous system immediately overlies the old red sandstone; in Durham, the new red sandstone overlies the coal; in Yorkshire, the oolite overlies the new red sandstone, and the chalk the oolite; in Kent, the tertiary strata overlie the chalk; and thus, though we do not find every series at one and the same place, we always find them occurring in the order above described. The old red sandstone and silurian, for instance, might be absent, and the coal in this case might rest on the clay-slate; or the new red sandstone and oolite might be absent, and chalk might rest on the coal; or even all of these might be wanting, and chalk immediately overlie the clay-slate. Still, there would be no reversal—a higher system would be overlying a lower; and the inference to be deduced would simply be, that the region in which any set of rocks was wanting, had been dry land during the deposition of these strata. This order of succession, or *superposition*, as it has been termed, is the great key to the solution of all geological problems; and so soon as an observer has fixed one point in the series, he knows infallibly his position in the history of the crust, no matter in what region he may be placed, or what the distance from the scene of his former observations. In determining his position, *mineral characteristics* may sometimes fail him, and a sandstone of the oolite may scarcely be distinguishable from a sandstone of the coal-measures; but *palæontological characteristics* are so constant, that the moment he discovers a few fossil organisms, he is at once enabled to pronounce whether he is on an oolitic or on a carboniferous district.

104. The constancy of fossil characteristics has suggested the classification of the sedimentary rocks into certain great divisions, according to the types of living beings that predominated during the successive stages of deposition; and as geological investigation advances it is more than probable that we must abandon our rock groups and systems, and adhere to great *life periods* as the

true exponents of the world's progress and history. To our conceptions, vitality is a higher effort of creative energy than mere inorganic matter. It is a more sensitive instrument, as it were; hence its value as an index to geological change and geological duration. As yet these life periods are not very clearly determined, and as we will have occasion to advert to them again and again, it may be enough for the student, at this stage, merely to tabulate their order in connection with the rock-systems already alluded to :—

CAINOZOIC PERIOD (*Recent Life*),	Post-tertiary or present epoch. Tertiary epoch.
MESOZOIC PERIOD (*Middle Life*),	Cretaceous epoch. Oolitic epoch. Triassic epoch.
PALÆOZOIC PERIOD (*Ancient Life*),	Permian epoch. Carboniferous epoch. Devonian epoch. Silurian epoch.
AZOIC PERIOD (*Void of Life*),	Non-fossiliferous epoch, or Metamorphic system.

Instead of this arrangement it has been proposed by some to substitute the following as sufficiently distinctive and more philosophical :—

NEOZOIC PERIOD (*New Life*),	Post-tertiary or present epoch. Tertiary epoch. Cretaceous epoch. Oolitic epoch. Triassic epoch.
PALÆOZOIC PERIOD (*Ancient Life*),	Permian epoch. Carboniferous epoch. Devonian epoch. Silurian epoch.
HYPOZOIC PERIOD (*Beneath Life*),	Metamorphic rocks in which fossils have not yet been detected.

In either case, all that is meant by the arrangement in the mean time is, that during certain epochs there was a certain typical resemblance among the beings then peopling the globe; that down to the chalk, fossil species closely resemble those now existing (*cainos*, recent, and *zoè*, life); from the chalk to the Permian the departure from recent types was greater (*mesos*, middle); and that from the Permian downwards the species were altogether distinct from the recent, and different in a majority of instances from those of the middle period (*palaios*, ancient). The term Neozoic (*neos*, new) merely expresses the distinction in broader terms; while Hypozoic (*hypo*, under) implies only

the subjacent position of the metamorphic rocks—leaving it to future research to determine whether they are absolutely void of fossils or not. Whatever view may be adopted, the student should remember—and he cannot be too early cautioned ever to bear in mind—that throughout the whole of creation there is only ONE SYSTEM, *and that in time past, as in time present, every aspect* of nature gives evidence of only ONE all-pervading, all-directing Mind. The matter of the universe may undergo change of place, appearance, and arrangement; still it is the same matter, subject to the same laws that have operated through all time. The plants and animals on this globe may assume different specific aspects at different epochs and under different conditions; still they are constructed on the same plan and principle, and the laws which influence their being now are identical with those that have governed vitality since the dawn of creation. Without this uniformity of law, the study of nature would be impossible. There is only ONE GREAT SYSTEM in creation, and the periods and systems of the geologist must be regarded as mere provisional expedients *towards the interpretation of the continuous evolution* of that creative system.

Igneous or Unstratified Groups.

105. Besides these classifications of the stratified rocks according to their mineral characters, their fossil contents, and their order of superposition, there has also been attempted an arrangement of the unstratified or igneous masses. These, we have already seen, appear among the sedimentary strata without order or arrangement—heaving them out of their original horizontal positions, breaking through them in mountain masses, or overspreading them after the manner of liquid lava. Owing to this irregularity of origin, they are often better known by their mineral composition than by their order of occurrence. Still it is customary to speak of them as GRANITIC, TRAPPEAN, and VOLCANIC; meaning, by the term Granitic, the igneous rocks which, like granite, are usually found associated with the older strata; by the term Trappean, the igneous rocks most frequently associated with the secondary and tertiary strata; and by the term Volcanic, those that have made their appearance during the present epoch. It is true that it is often next to impossible to distinguish certain volcanic rocks from the more ancient traps; and it is also well known that granitic effusions occur among secondary strata. Still, taking the three classes on the

large scale, and looking at the stratified systems with which they are usually associated, it will be found of essential service to retain the subjoined classification :—

VOLCANIC,	Lava, trachyte, scoriæ, &c., associated with recent accumulations.
TRAPPEAN,	Trap-tuff, amygdaloid, greenstone, basalt, &c., associated for the most part with tertiary and secondary strata.
GRANITIC,	Granite, syenite, porphyry, &c., associated in greatest force with transition and primary strata.

With these distinctions we close, in the mean time, our remarks on the divisions of the stratified and unstratified rocks—deferring minuter details till we come to discuss the respective systems. All that is necessary for the student at this stage is to remember the broader lines of distinction ; to recollect that the preceding classification refers more especially to the strata of the British Islands ; and to hold it in some measure provisional till geologists have been enabled to examine and co-ordinate more closely the rock-systems of other regions.

NOTE, RECAPITULATORY AND EXPLANATORY.

106. The purpose of the preceding chapter has been to exhibit the classification adopted by geologists in describing the various rock-formations which constitute the crust of the globe, and more especially as developed in the British Islands and the continent of Europe. The basis upon which such a classification is founded is either mineral composition, fossil contents, or order of superposition. By these aids the order of sequence among the stratified rocks has been pretty accurately ascertained ; hence the subdivision of formations into systems, groups, and series. In making such an arrangement, it is not affirmed that any portion of the crust exhibits these systems one above another like the coats of an onion, but simply that one series always succeeds another in determinate order, and that though several series may be wanting in certain districts, such series as are present are never found out of their order of succession. Beginning at the surface, we have, in descending order—

1. Post-tertiary, or recent accumulations.
2. Tertiary strata.
3. Cretaceous or chalk system.
4. Oolitic system.
5. Triassic, or upper new red sandstone.
6. Permian, or lower new red sandstone.
7. Carboniferous system.
8. Old red sandstone, or Devonian system.
9. Silurian system.
10. Metamorphic system.

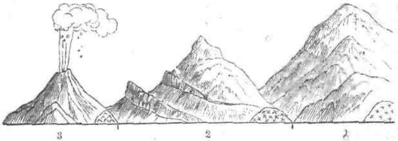
The first nine of these systems are spoken of as the *Fossiliferous Rocks*, because they contain, less or more, the remains of plants and animals; the rocks of the last, which contain no traces of vegetable or animal life, are termed the *Non-fossiliferous*. Referring to the fossil contents of the different strata, the term *Neozoic* (new life) is applied to the recent, tertiary, and upper secondary epochs; the term *Palæozoic* (ancient life) to the lower secondary and transition epochs; *Azoic* (or destitute of life), to the primary or non-fossiliferous epoch; or, avoiding all opinion as to the absence of fossils from these rocks, the term *Hypozoic* (beneath life) simply points out their position as lying under those systems which are decidedly fossiliferous. As with the stratified, so with the unstratified rocks: some acknowledged plan of classification is necessary, and that which arranges them into *Volcanic*, *Trappean*, and *Granitic*, is perhaps the most intelligible, as well as the most generally adopted. By employing the classification above indicated, every geologist, in treating of the rocks of a district, speaks a language intelligible to other geologists, and all the more intelligible that it is a classification founded on facts in nature, and not on mere arbitrary or technical distinctions.

107. The steps by which the preceding arrangements have been arrived at have been adverted to in the context, that the student may comprehend more fully the application of many of the terms employed. Knowing the progress of his science, he will be at no loss to comprehend the import of such phraseology as "rocks of the transition period," "aspects of primary districts," "fossils of the younger secondaries," "fauna of the tertiary epoch," and many others that are in daily use among working geologists. The whole scheme of arrangement is one embodying ideas of progress and gradation; hence we speak of "lower and upper palæozoics;" "older and younger secondaries;" forms that die out at the "close" of one epoch or appear at the "dawn" of another; and of species that are characteristic of some definite "stage" or "horizon" in some particular system. To impart a thorough concep- he plan of classification and of the spirit that pervades it, ct of the foregoing chapter; and the student

who has mastered this may be contented to leave the names of minuter subdivisions to a future stage of his progress. For the sake of easy reference, however, and in some measure to serve as an index to the descriptions of the several systems, we subjoin a tabular outline of the arrangement of British rocks as at present accepted by our leading geologists—referring the student for some curious historical details to the opening chapters of Sir Charles Lyell's *Principles of Geology*, and for minuter subdivisions to the Table of Contemporary or Equivalent Deposits, appended to CHAP. XVIII. of the present volume:—

Systems.	Groups.	Periods.
POST-TERTIARY.	In Progress. Recent.	CAINOZOIC.
TERTIARY.	Pleistocene. Pliocene. Miocene. Eocene.	
CRETACEOUS.	Chalk. Greensand.	MESOZOIC.
OOLITIC.	Wealden. Oolite. Lias.	
TRIASSIC.	Saliferous marls. Muschelkalk. Upper new red sandstone.	
PERMIAN.	Magnesian limestone. Lower new red sandstone.	PALÆOZOIC.
CARBONIFEROUS.	Coal-measures. Millstone grit. Mountain limestone. Lower coal-measures.	
DEVONIAN.	Yellow sandstones. Fossiliferous limestones and schists. Red conglomerates, sandstones, and cornstones. Grey fissile sandstones.	
SILURIAN.	Upper silurian. Lower silurian. Cambrian (?).	
METAMORPHIC.	Clay slate. Mica schist. Gneiss and granitoid schists.	AZOIC, OR HYPOZOIC.

Range of Volcanic (Post-Tertiary to Cretaceous); *Range of Trappean Rocks* (Cretaceous to Silurian); *Range of Granitic Rocks* (Tertiary to Metamorphic).



VII.

THE IGNEOUS ROCKS:

COMPRISING—1, THE GRANITIC; 2, THE TRAPPEAN; AND, 3, THE VOLCANIC; WITH THEIR RELATIONS TO THE STRATIFIED FORMATIONS.

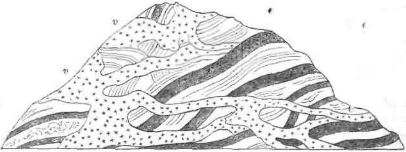
108. As repeatedly stated in the preceding chapters, the igneous rocks have no determinate position in the crust of the earth; hence their minor value as exponents of geological conditions. Unlike the stratified rocks, they have no order of superposition; and, unless in some rare and accidental instances, they contain no organic remains. On the other hand they derange, break through, and flow over the stratified formations—and this, apparently, at no regular intervals of time, or in no determinate manner. Though thus throwing no light on the vegetable and animal phases of the globe, nor supplying any idea of successional order in point of time, they are still of importance in demonstrating the unity of geological agency; and their relative positions as well as structure and composition often enable us to explain phenomena which would otherwise remain unsolved. The study of the stratified formations and their imbedded fossils is no doubt the most expressive as it is the most attractive department of the science; but he who neglects the igneous rocks and their concomitant appearances, must ever remain ignorant of many of the higher deductions of geology.

109. Respecting the origin of the igneous, or *pyrogenous* rocks as they are frequently termed (literally, "fire-formed," from the Greek *pyr*, fire, and *ginomai*, I am formed), geologists have yet no satisfactory theory to offer—one class ascribing all igneous phenomena to some great central source of heat within the globe, and another attempting to account for their production by chemical unions among the primary constituents of the rocky crust. The former contend that the occurrence of volcanoes, earthquakes, escapes of heated vapours, and thermal springs, are by far too numerous and general to be accounted for on any principle of chemical union with which we are acquainted; and the latter, pointing to the violent evolutions of heat that accompany the decomposition of such bases as potassium, sodium, and calcium, argue for this view as more philosophical and more in accordance with natural law. The one theory is known as the *mechanical*, the other as the *chemical*, and each has had its own able and earnest supporters; but we shall defer further notice of their arguments till the student is presumed to be acquainted with the nature of the rocks to which their reasonings refer. Meanwhile, admitting the igneous origin of the rocks and their violent discharge from deep-seated sources, we shall proceed to describe their characters and relations as classified under the heads GRANITIC, TRAPPEAN, and VOLCANIC.

I.—GRANITIC ROCKS.

110. *Granite* (*granum*, a grain) is so named from its granular composition and aspect. The typical granite is a compound of quartz, felspar, and mica, arranged in distinct grains or crystals; and all rocks partaking of the character and appearance of granite are termed *granitic*. The epithets *granitoid* and *granitiform*, also in use by geologists, are applied to rocks having some resemblance to granite, though not decidedly of granitic nature, nor even, it may be, of true igneous origin. The granitic rocks, properly so called, are all highly crystalline; none of their crystals are rounded or water-worn; they present no traces of deposition or stratification; they occur in the crust as mountain masses and veins, bursting through and displacing the sedimentary rocks; and they indurate and otherwise alter (as all heated masses do) the strata with which they come in contact. From these circumstances they are held to be of igneous origin; and, as far as geologists have been able to discover, they are the most deeply-seated of all rocks—forming, as it were, the floor or foun-

dation for all the superincumbent formations. As the earliest of igneous rocks, they are generally found associated with primary and transition strata, tilting them up on their edges, bursting through them in dykes and veins, and variously altering their positions and mineral character. Though occurring most abundantly among primitive strata, granitic outbursts may be found



Granitic Veins (*v v*) traversing Gneiss at Cape Wrath—M'Culloch.

among rocks of all ages, but certainly not as a marked and general feature of the period. In the island of Arran, for example, granitic dykes are found traversing rocks of the carboniferous, if not of the new red sandstone period, and in the Alps granitic outbursts and upheavals are associated with strata of cretaceous age; but these are exceptions, and not the rule—the great epoch of granitic intensity being that which terminated with the deposition of the silurian strata.

111. Whether occurring in veins or mountain-masses, the structure of granite is irregular and amorphous. In its texture it varies from a close-grained compact rock to a coarse and loose aggregation of primary crystals. In the composition of granitic rocks there is also considerable variety, and the student will best learn to discriminate the different species by the examination of actual specimens. Ordinary *granite* is composed of crystals of felspar, quartz, and mica,—is of a greyish colour when the crystals of felspar are dusky-white, and reddish when they are coloured by the presence of iron. When the dark glassy mineral called hornblende takes the place of the mica, the rock is known by the name of *syenite* (from Syene in Upper Egypt); and when both mica and hornblende are present, the compound is known as a *syenitic granite*. Occasionally talc supplants the mica, and then the admixture of felspar, quartz, and talc is known by the name of *protogine* (literally, first-formed)—a term by no means happily chosen, as many of these talcose granites (like those of the Alps)

occur in connection with rocks of secondary formation. The term *hypersthenic granite* is applied to an admixture of quartz and hypersthene, with scattered flakes of mica; and *graphic granite* is a binary compound of felspar and quartz—the quartz being disposed through the felspar matrix like the lines of Arabic writing—hence the name. Another fine-grained compound of felspar and quartz, with minute scales of mica, is known by the name of *pegmatite* (*pegma*, compacted); and *porphyritic granite* is the term employed when, in addition to the crystals composing the general mass of the rock, there are indiscriminately mingled through it larger and independent crystals of felspar, as in the Dartmoor granites of Devonshire.

112. Besides the preceding there are other granitic compounds, in all of which felspar, quartz, mica, hornblende, and hypersthene are the principal ingredients, and talc, steatite, chlorite, schorl, and actynolite the accidental or modifying minerals. It is enough, however, for ordinary purposes to be able to discriminate those already mentioned; and to remember that granites are often spoken of as *binary*, *ternary*, and *quaternary*, according to the number of simple minerals which enter into their composition. Thus, graphic granite, as composed of felspar and quartz, is a binary; ordinary granite, of felspar, quartz, and mica, is a ternary; and syenitic granite, of felspar, quartz, hornblende, and mica, is a quaternary compound. There are, however, many blendings of these, one into the other; and in the same hill, or even in the same quarry, we may find some half-dozen varieties of granite, if distinctions are to be founded upon the greater or less abundance of any one constituent mineral.

113. As an igneous rock, granite occurs either in eruptive mountain-masses, in dykes, or in veins. In general, granitic dykes present a very different aspect from the granite they traverse—hence we may have a small-grained compact rock traversing one of large granular texture; or one in which several accidental minerals are developed that do not occur in the main mass. Thus, we have dykes and veins of glassy *quartz*, with a few scales of mica; of hornblende with a little quartz (*hornblende rock*); of hypersthene with a little felspar (*hypersthene rock*); of glassy felspar with a little quartz; or of felspar with large macles of mica. It is from these veins that we derive the "crystallised granites" of the mineralogist, the felspar of commerce, the schorl, tourmaline, rock-crystal, garnet, and other gems prized by the lapidary and jeweller. Another of the eruptive rocks of the granitic and metamorphic periods is that known by the name of

serpentine—an intimate admixture of various magnesio-siliceous *ingredients, which produce a speckled or mottled appearance*, resembling a serpent's skin; hence the name. Steatite, chlorite, diallage, augite, crystalline limestone, &c., are common ingredients in many serpentines; hence the variety of aspects they assume, and hence also the doubt that is sometimes started as to their igneous or metamorphic origin.

114. However complicated the mineral admixtures of granitic rocks, and however varied their aspects, there are several features which they preserve in common, and which serve to distinguish them from the later igneous rocks. For instance, they are more crystalline, or rather granular-crystalline, than any other variety of igneous rock; they are never vesicular, cellular, or porous, like traps and volcanic lavas; they exhibit less structure than trappean rocks, being generally massive or cuboidal, and void of that columnar structure so common in basalts and greenstones; they are never amygdaloidal like traps, conglomerated or brecciated like trap-tuffs, or scoriaceous like volcanic tufa. They seem to have been formed at greater depths or under greater pressure than either traps or lavas; hence they are spoken of as *plutonic* in contradistinction to *volcanic*, which may be originated under the open air. For similar reasons they are classed by some American geologists as *pyro-crystalline*, in contradistinction to the traps and lavas, which are regarded as *pyro-plastic*—a distinction which the student will find, as he advances, to be more apparent than real.

[Admitting the general doctrine of the igneous origin of granite, the student would do well to remember that the granitic, like all other deep-seated rocks, may have undergone less or more metamorphism since the time of their formation. Heat, pressure, chemical action, and other internal forces are continually producing this change, and from this cause may have arisen the more crystalline and uniform texture of granites as compared with traps and lavas. At all events, it is safer to fall back on this hypothesis, than appeal to "aqueous conditions of formation" which are sometimes advanced to account for certain phenomena in the texture and crystalline arrangement of granitic compounds, but which are otherwise wholly at variance with the disruptive character of these rocks as evidenced in their relations to the overlying gneiss and mica-schists.]

Physical Aspects.

115. Granitic rocks are widely distributed, and form the principal mass of the most extensive mountain-ranges in the world. The Grampians in Scotland, the mountains of Cumberland, Devon, and Cornwall in England, the Wicklow mountains in Ire-

land, the Dofrafelds in Scandinavia, the Alps in Switzerland, the Pyrenees in Spain, the Oural and Himalayan ranges in Asia, the Abyssinian and other chains in Northern Africa, the hills of Damara and Namqua Land in Southern Africa, the central range of the Island of Madagascar, and the Andes in South America, are all less or more composed of granitic rocks, or of primary strata thrown up and altered in mineral character by these granitic intrusions. They form, as it were, the skeleton of our chief mountain-chains and table-lands; and while in many instances they have been the immediate instruments of elevation, in others they were undoubtedly the islands and continents whose waste went to constitute the strata that now envelop their bases.

116. The physical aspect of purely granitic tracts is, on the whole, dreary and monotonous. Huge rounded hills with little irregularity of outline, flat or slightly undulating moorland expanses, and bald woodless crags, are the common features of the districts where granite alone prevails. Partly from the barren nature of their scanty soil (decomposed quartz and felspar), and partly from their high and elevated condition as mountain-chains and table-lands, these granitic areas are generally bleak and inhospitable, presenting few facilities for agricultural improvement or amenity. Draining and shelter have done much to reclaim; but the granitic moorland seems almost beyond the power of human labour and ingenuity.

Industrial Products.

117. The industrial purposes to which granitic rocks are applied are alike numerous and important. As a durable building-stone for heavy structures, like docks, bridges, lighthouses, and fortresses, the harder varieties of granite are invaluable; and for these, as well as for street purposes, large quantities are yearly quarried in Aberdeenshire, Argyll, Wicklow, and other districts. In some towns, as Aberdeen, granite forms the ordinary building-stone; and those who have witnessed the public structures of that city will see how well it is fitted for the highest requirements of architecture. As an ornamental stone for monuments, halls, chimney-slabs, pillars, pedestals, and the like, some varieties of granite are rapidly coming into use—the beauty and sparkle of their variegated texture, and the perfection to which they can be cut and polished, rendering their adoption peculiarly desirable. As yet Aberdeen is the headquarters of this species of manufacture—the whitish-grey of Rubislaw, the bluish-grey of Cairngall,

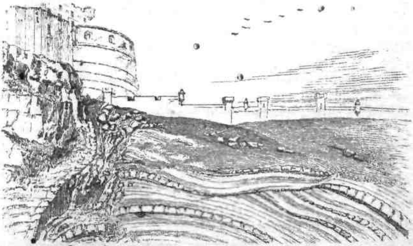
and the reddish flesh-coloured of Peterhead, being the most esteemed sorts; but some of the porphyritic and marble-like varieties of Argyllshire and the Western Islands seem also to be coming into demand. Some felspathic granites, like those of Cornwall and Devon, are easily decomposed when exposed to the weather, and in this state produce a fine impalpable clay (silicate of alumina—silica 60, alumina 40), known as *Kaolin*, or China clay, and largely employed in the manufacture of the finest pottery and porcelain, statuettes, buttons, and the like. About 10,000 tons of the finest, and nearly 30,000 of the commoner kinds, are said to be annually collected and prepared for this purpose in the counties of Devon and Cornwall. *Felspar*, as a vein-stone, is likewise worked for pottery purposes, some varieties producing the finest and most durable enamels; and hence also its application in the manufacture of artificial teeth, and similar compounds. *Apatite*, or crystallised phosphate of lime, is another mineral product found in veins traversing the earlier igneous rocks (largely, as in Norway and Spain), and promises shortly to be of vast value in the preparation of artificial manures. Among the minor products of granitic rocks and veins may be enumerated *mica* (when in large plates, as a substitute for glass; hence the term "Muscovy glass," from its being used in Russia); *talc; meerschaum* (a carbonate of magnesia), used in the manufacture of porcelain and for tobacco-pipes; *asbestos* and *potstone*, to be afterwards noticed; *rock-crystal*, the amber-coloured varieties of which are known as "cairngorms" (from the mountain of that name in Aberdeenshire); *tourmaline; beryl; garnet*, and other precious minerals.

II.—TRAPPEAN ROCKS.

118. The term *trap* (from the Swedish *trappa*, a stair) was originally applied to those igneous rocks which give to many hills of the secondary period a terraced or step-like appearance. Most of these rocks seem to have been formed under water, here spread out as volcanic dust and ashes, there as flows of lava, and anon interstratified with true sedimentary matter. It is to these successional flows of igneous matter, and the subsequent unequal degradation of the interstratified aqueous rocks, that the trap-hills owe their stair-like appearance. As the granite rocks were generally associated with the older strata, so the trappean rocks are usually connected with the secondary—throwing them up on the sides of hills, breaking through them in dykes and veins, and spreading over them in sheet-like masses. The student, however,

is again reminded that this distinction is merely provisional, and for the sake of more easy comprehension. Granitic outbursts appear in connection with oolitic and cretaceous strata; and it is often impossible to distinguish between the traps of ancient and the trachytes of more modern volcanoes. Still, as a whole—and herein lies the value of our classification—the granites are more ancient than the traps, and the traps than the volcanic trachytes and lavas.

119. In their structure and composition, the trap-rocks are extremely varied—some being compact and crystalline, like basalt and greenstone; others soft and earthy, like certain trap-tuffs and claystone porphyries. Indeed, there is no class of rocks more puzzling either to the mineralogist or to the geologist, their varieties being so numerous, and their relations to the strata being often so intricate and deceptive. The more crystalline varieties are known as basalts, greenstones, clinkstones, compact felspar, and felspar-porphyries; the earthier varieties, as claystones, claystone-porphyries, amygdaloids, trap-tuffs, and wackès. Mineralogically speaking, they are chiefly composed of felspar, hornblende, and augite, with admixtures of hypersthene, olivine, green-earth, quartz, clay, and iron. In their structure and texture they give greater evidence of their pyrogenous origin—being frequently cellular or vesicular like lava, scoriaceous like volcanic ashes, and brecciated like the tufaceous accumulations round the craters



Basaltic Clinkstone of Edinburgh "Castle Rock" breaking through, contorting, and otherwise altering the stratified Shales and Sandstones of the Lower Coal-Measures

of modern volcanoes. In their columnar and spheroidal arrangement they exhibit more structure than the granites, and point

distinctly to their origin as the stony products of cooling and consolidation from igneous fusion. Their action upon the stratified rocks is also more decided and perceptible: here we see them bursting through and producing faults and fissures; there tilting up the strata at acute angles, or bending and flexuring them in a variety of ways; and generally at the points of contact indurating with greater or less intensity, so as to convert sandstones into quartzites, limestones into crystalline marbles, coal into anthracite, and clays and shales into chert and porcelain-jaspers. Indeed, in their entire relations they are so exactly analogous to modern volcanic rocks, that geologists feel no hesitation in ascribing to them a similar pyrogenous origin. As was forcibly remarked by Sir James Hall, now more than sixty years ago,—"The analogy between the two classes seems to hold through all their varieties; and I am confident there is not a lava of Mount Etna to which a counterpart may be produced from the whinstones of Scotland."

120. The trappean rocks being thus of decidedly igneous origin, many of them must have been ejected after the manner of molten lava; some scattered abroad as showers of volcanic dust and ashes; while others are as evidently the broken and half-fused fragments of the associated strata. Heterogeneous in their origin as modern volcanic products, they are rendered more varied by the circumstance of some having been formed at great depths, some under the pressure of water, and others having been re-fused and re-ejected during subsequent eruptions. Much of their perplexing variety of texture seems also to have arisen from the slowness or rapidity with which they have been cooled; and we know from the experiments of Sir James Hall and Mr Gregory Watt, that the same mass which will become a glassy obsidian when suddenly cooled, will pass into a stony basalt under a slower process, and into a soft earthy tufa if the cooling be prolonged through a still more gradual series of stages. Thus, running by imperceptible degrees into each other, it is often impossible to assign to some of the trap-rocks an exact specific place, and the geologist must content himself by taking as his guide the most obvious distinction that presents itself. For ordinary purposes the trap-rocks may be conveniently arranged under the *augitic*, or those in which the mineral augite predominates; the *felspathic* where felspar is the chief ingredient; *porphyries* where various minerals intermingle; *amygdaloids* where the cellular cavities of the mass have been filled by infiltrations of other mineral matter; and *tufas* where the texture is soft, porous, or earthy. Adopting this view, we have the following enumeration, which is sufficiently comprehensive for the ordinary purposes of geology:—

121. The *basalts* are the most compact, hardest, and heaviest of the trap-rocks; they are of a dark colour, close-grained texture, and often appear in arrangements more or less columnar, like that of the Giant's Causeway, Fingal's Cave in Staffa, and Samson's Ribs near Edinburgh. They are essentially augitic, usually enclose small spherical crystals of olivine (so called from its olive-green colour), and are more or less impregnated with iron. The *greenstones* (*whinstones* of Scotland) are less compact, more granular, exhibit distinctly their component crystals of hornblende, augite, hypersthene, &c., often contain sulphuret of iron, and are usually massive or tabular in their structure. It is customary to speak of them as hypersthenic greenstones, augitic greenstones, &c., according to the predominating mineral; and many of them are porphyritic in their texture—hence we have *greenstone porphyries* or *porphyritic greenstones*. Trap compounds, or greenstones essentially composed of augite and felspar, are sometimes (adopting Continental nomenclature) designated *dolerites;* while those chiefly composed of hornblende and felspar are termed *diorites*. The *clinkstones* or *phonolites* (*phonos*, sound, and *lithos*, stone), differ little from the basalts in composition, but are less compact, and break up into slaty-like fragments, and emit a ringing metallic sound when struck by the hammer,—hence their name. These three species of trap often graduate so imperceptibly one into the other, that geologists are under the necessity of adopting compound terms, like *basaltic clinkstone*, for example, to designate such a rock as that on which the Castle of Edinburgh is founded. The felspathic division of the trap-rocks also presents many varieties, and contains most of the porphyries properly so called. Thus, *compact felspar*, or *felstone*, is a compact paste or basis of felspar, with occasional disseminated crystals; and *felspar porphyry* has also a basis of compact or crystalline felspar, with large independent crystals disseminated through it. Closely allied to the felspars are the hornstones and pitchstones—*hornstone* and *hornstone porphyry* being compact flinty compounds, hence known as *petro-silex* or rock-flint; and *pitchstone* and *pitchstone porphyry* being siliceo-aluminous compounds having a compact texture and pitchy vitreous lustre. Neither the hornstones nor pitchstones occur in massive abundance, being generally found in traversing dykes and veins, like those of Arran and Ayrshire. The *porphyry* of the mineralogist consists of a reddish felspar basis with disseminated crystals sometimes of the same hue, and at others of a whitish or flesh-colour; but its variations are so numerous, that it is better to consider the term "porphyritic" as characteristic of a peculiar

composition in many rocks, than a rock *per se*. *Claystone* is a calcined-looking rock, composed essentially of earthy felspar; and it becomes *claystone-porphyry* when crystals of glassy felspar are imbedded in its mass. The *amygdaloids* are rather earthy in texture, have been originally vesicular, and are so named from the almond-shaped concretions (*amygdalon*, an almond) of calc-spar, agate, chalcedony, jasper, &c., which now fill the vesicular cavities; and the *trap-tuffs* and *wackes* occur in every gradation of texture, from soft scoriaceous masses to compact aggregations of rocky fragments cemented together by igneous matter. The *trachytes*, or *greystones* as they are sometimes termed, are greenish-grey varieties, indistinctly crystalline or earthy, and so named from the rough, harsh feel (*trachys*, rough) they have under the finger; but they belong to the volcanic rather than to the trappean group, and mark, as it were, the transition from the one epoch to the other. Indeed, as will be afterwards seen when we come to discuss the stratified systems and their associated igneous rocks, there appears to be something like a chronological development among the species of trap rocks—a subject which will require long years of patient research before it can be invested with any degree of certainty or generalisation.

Physical Aspects.

122. The geographical area occupied by the trap-rocks is very extensive, there being few secondary districts in which they do not rise up, either in undulating conical heights, or in terrace-like hill-ranges. Indeed, all the older secondary regions—that is, those occupied by the old red sandstone and carboniferous systems—owe their surface configuration chiefly to manifestations of trap. Much of this trap is of contemporaneous origin with the sedimentary rocks among which it occurs, and is of course interstratified with these deposits; but a great portion also is of posterior date, and in this case occurs as disrupting and overlying masses. To enumerate the districts in which trappean compounds occur, would be to map out the countries occupied by the whole transition, secondary, and tertiary systems. In our own country, the Sidlaw, Ochil, Pentland, and Lammermuir ranges in Scotland; the Cheviot, Cumberland, Welsh, and Derbyshire hills in England; and most of the hills in Ireland, are of true trappean composition—that is, of variable masses of one or other of the species enumerated in the preceding paragraph.

123. The scenery produced by assemblages of trap hills is often

extremely picturesque and beautiful—their undulating outlines, step-like ascents, abrupt crags and cliffs, and detached conical eminences, presenting a much greater variety of scenic aspect than is produced by those either of granitic or of volcanic origin. They are "hills" rather than mountain-ranges, and consequently produce, within narrower limits, all that diversity of surface which is ever so pleasing to the human eye, while their moderate height prevents that cold sterility which renders the heights of primitive mountains often so dreary and monotonous. In addition to this, the soil produced by the decomposition of many traps is so genial and productive, and is so well drained by their natural joints and fissures, that the term "trap-district" is usually regarded as synonymous with amenity and fertility.

Industrial Products.

124. The industrial purposes to which trap-rocks are applied are numerous enough, but not of prime importance. Some basalts and greenstones make very durable building materials, but the difficulty of dressing them into proper shape, combined with their dingy and unattractive colours, prevents their extensive use. The same may be said of the felspar-porphyries, clinkstones, and amygdaloids, which are rarely employed where sandstones or limestones can be obtained. Their hardness, however, renders them peculiarly fitted for road and street material; hence their extensive use in causewaying and macadamising—several of the greenstones successfully competing with the granites in this respect. Before the improved manufacture of fire-bricks some open-textured varieties were largely used for the linings and soles of ovens; and some of the closer-grained greenstones and basalts have been employed by the Hindoos, Persians, and Egyptians for sculptural purposes. From the *geodes* (that is, sparry cavities) of the amygdaloids and trap-tuffs are obtained most of the agates, jaspers, chalcedonies, and carnelians, made use of by the lapidary and jeweller. Indeed, the so-called "Scotch pebbles" are mainly derived from the amygdaloids of the Kilpatrick, Sidlaw, Ochil, and Crieff hills—being sometimes quarried from the rock, but generally found among the weathered debris, or from the gravel of the adjacent rivers and sea-shores. Few metalliferous veins are found traversing rocks of trappean origin, though they are evidently connected as a producing cause with many of the ore-veins of the mountain and magnesian limestones. Perhaps the most notable metallic product occurring in trap-rocks is the *native copper* of

Canada and North America, which occurs in plates and strings and blocks often of large dimensions. A similar native copper, in irregular plates and strings, occurs in the traps of Dumbartonshire; but it is too sparingly disseminated to be mined with profit.

III.—VOLCANIC ROCKS.

125. All the igneous rocks already described are, in one sense, *volcanic*—that is, have been produced by the agency of heat in a manner analogous to that of existing volcanoes. For the sake of classification, however, it is better to limit the term to such rocks as are now in process of formation, or have been formed since the close of the tertiary epoch. It may be difficult, in some instances, to distinguish a mass of trachytic lava from one of trachytic trap-tuff; but when the mass is viewed in connection with its associated rocks, its origin becomes readily apparent, and there is generally as little difficulty in distinguishing between recent volcanic products and trappean compounds, as there is in distinguishing between trap and granite. Volcanic rocks are, therefore, essentially products of the modern period, and are found, like the older igneous rocks, either elevating, bursting through, or overlying the stratified formations.

126. A volcano (*Vulcanus*, the god of fire) has been described as "a more or less perfectly conical hill or mountain, formed by the successive accumulations of ejected matter in a state of incandescence or high heat, and having one or more channels of communication with the interior of the earth, by which the ejections are effected." This definition is a somewhat restricted one; for, geologically speaking, all matters discharged from the crust of the earth by the action of heat are regarded as *volcanic* or of volcanic origin. These substances make their appearance either as solid matter, as mud, water, vapour, or as gases; and, when cooled down and consolidated, produce a variety of rock-products, which we shall now describe:—*Lava* is the name commonly given to all melted rock-matter ejected from active craters, and which, when cooled down, forms varieties of tufa, trachyte, trachytic greenstone and basalt, according to the varying proportions of felspar, hornblende, augite, and according to the slowness or rapidity with which the mass is cooled. The more rapid the process of cooling, the more compact the rock; and thus we have among volcanic products, just as among trappean, every variety of texture, from that of a glassy basalt to a granular trachyte or *greystone*, and from that to a soft earthy tufa. *Obsidian*, or volcanic glass, is a vitreous lava of

various shades of colour, and in many instances is scarcely distinguishable from the product of the glass-furnace. Indeed, so

View of Mount Etna—Conical Aspect of Volcanoes

thoroughly glassy is its nature, that its name is said to be derived from the Greek word *opsianos*, in allusion to its use among the ancients as a material for mirrors. *Pumice* (*spuma*, froth or scum) is a light porous rock, evidently produced by the disengagement of gases in the mass while in a state of fusion ; in other words, the solidified froth or scum of molten rock-matter. It is often so light as to float on water, is of various shades—the finer varieties having a pearly or silky lustre, and fibrous texture. The pumices are closely allied to the obsidians in composition, and appear to be the same substance rendered porous and fibrous by the extrication of steam and gases. To the same group also belong the *pearlstones*, so called from their pearly lustre, and which hold an intermediate place betweeen the pumices and obsidians—being more compact than the former and less vitreous than the latter. Several pearlstones are almost undistinguishable from the pitchstones of the trap group ; but it is better to limit the terms as we have indicated—retaining the one for the modern, and the other for the more ancient compounds. *Scoriæ*, *cinders*, *ashes*, and the like, are of the same mineral composition as the solidified lava, and seem to be produced by the explosive force of steam or other gases. These scoriaceous compounds are sometimes light and cindery, like

those found floating on the surface of lava streams; at other times they are heavy and vitreous, being ejected in a stony state, and when the fragments are of some size, are known as *volcanic bombs*. What is termed *volcanic sand* appears to be finely comminuted scoriæ, and is found in scattered accumulations in almost all volcanic districts. *Volcanic dust*, ejected from active craters, and often carried to great distances by wind, is a compound of argillaceous, calcareous, magnesian, and siliceous earths, usually tinged with iron, and capable of forming a pasty mass with water. It is this pasty matrix that binds together scoriæ, sand, lapilli (small stones), and the like, constituting what are then known as *volcanic tufas, breccias, puozzolanas* (from Puozzoli, near Naples), and the *tarras* or *trass* of Rhenish Germany. *Volcanic mud*, which bubbles out from many fissures and openings (known as mud-volcanoes), is a product of considerable magnitude in some regions; has a fœtid sulphurous odour; and in cooling and solidifying is often found to contain crystals of sulphur and gypsum. Jets of hot water (like the *geysers* of Iceland), and those of steam (like the *suffioni* of Italy), are important volcanic demonstrations, and usually contain in their waters solutions of rock-substances, as silica, lime, borax, &c.; while the gaseous discharges (*moffeti*) are usually carbonic acid gas, sulphuretted hydrogen, and sulphurous acid. Most of the sulphur of commerce is derived from volcanic districts; and the *solfataras*, or sulphurous-vapour-springs, are amongst the most peculiar and persistent of their phenomena. One of the most curious and abundant of rock-products in some volcanic regions is that known by the name of *palagonite* or palagonite-tuff—the variety from Iceland being described as a compound of silica, alumina, sesqui-oxide of iron, lime, magnesia, potassa, soda, and water, and so soluble that it cannot resist the action of the weakest acids, and is even partially dissolved by water.

127. All the products described in the preceding paragraph are found less or more in every volcanic region; and the mode in which they are discharged, their varying admixtures, and the different appearances they assume, according to the rapidity or slowness with which they are cooled, afford highly instructive lessons to the geologist. Here the explosive force of highly-heated vapours and molten matter breaks through and deranges the strata of the crust; there lava penetrates every fissure, or, issuing from some vent, flows down the mountain-side, filling up valleys, damming up river channels, and spreading over fertile plains: here scoriæ and ashes are showered forth, borne abroad by winds, and scattered over land and sea; there heated vapours

are perpetually exhaling from rents and fissures, and incrusting their sides with mineral and metallic compounds. Discharge after discharge from volcanic vents gives rise in time to mountains; or, if spread along the bottom of the sea, is in turn overlaid by true sediment, and thus produces alternations of aqueous and igneous rocks. The molten matter also cools unequally—here forming a porous pumice, there a rough open tufa; here a granular trachyte, and there a compact mass, scarcely distinguishable from basalt or greenstone. And just as igneous forces are acting at the present day under the eye of the observer in the production of volcanic rocks, so must they have acted in former ages in the production of trappean and granitic compounds; with this difference, that many of the latter have been formed at great depths and under great pressure, and have subsequently undergone internal changes to which volcanic or sub-aërial igneous rocks have not been subjected.

[The mode and results of volcanic action are very instructively described by the Rev. T. Coan in his account of an eruption from Mauna Loa, one of the active cones of the Sandwich Islands. The eruption took place during October 1856, and the following extracts from his letters cannot fail to impress on the mind of the student the magnitude as well as the variety of the rocky compounds that may arise from a single lengthened eruption:—"A fracture, or fractures, occurred near the summit of the mountain, which extended in an irregular line from the terminal point, say five miles down the north-east slope of the mountain. From this serrated and yawning fissure, from two to thirty yards wide, the molten flood rushed out and spread laterally for four or five miles, filling the ravines, flowing over the plains, and covering all those high regions from 10 to 100 or 200 feet deep. Along this extended fissure, elongated cones were formed at the points of greatest activity. These cones appear as if split through their larger diameter, the inner sides being perpendicular or overhanging, jagged, and hung with stalactites, draped with filamentous vitrifications, and incrusted with sulphur, sulphate of lime, and other salts. The outsides of these cones are inclined planes, on an angle from 40° to 60°, and composed of pumice, cinder, volcanic sand, tufa, &c. You will not, however, understand that these semi-cones were once entire, and that they have been *rent*. They are simply masses or ridges of cinder and dross deposited on each side of the fractures where the action is greatest, and where the greatest amount of fusion has been ejected. These ridges or scorified heaps and their substrata, together with the immense fields of refrigerated and uneven lavas for miles around, were all produced by ejections or *overflowings* from the fissures mentioned. *It is all a new deposit.*

While these immense floodings were going on laterally around the volcanic vents, incandescent streams were, of course, winding their way down the side of the mountain. These fiery streams, when united, formed a river some three miles wide on the side of the mountain, and in the plains at the base of the mountain it spread into a lake or sea from five to eight miles broad. Again it narrowed to two or three miles, and went into the woods, winding its way through the thicket, contracting and expanding, and eating the jungle till it came within five miles of Hilo—making in all a lava current (including windings) nearly seventy miles long! Now, after you leave the region of open fissures, near the summit of the mountain, all below

appears to be a flow on the surface. We can see no chasms or fractures except those *always found in the surface-flows. There is no visible evidence* that the old substrata had been fractured, except on the higher regions of the mountain. *The whole is a mere surface-flow, the fused lava finding its* way *under cover* down the mountain-side, and without showing itself at a single point save at the forward margin. The process is thus:—Lavas flowing on the surface and exposed to the atmosphere, unless moving with great velocity, as down steep hills, soon refrigerate on the surface, as water freezes first on the top. This hardened surface thickens, until it extends downwards 1, 10, 50, 100, or 200 feet as the case may be. Under this superstratum the lava remains liquid, the hardened cover protecting the fused stratum from the refrigerating influence of the atmosphere and thus facilitating its longitudinal or lateral progress. Consequently, at the termini, and sometimes along the margin of the hardened stream, you see the fusion gushing out in red lines and points, and in irregular masses; and, where the ground is not steep, pushing sluggishly on, like the creeping of a slug, or by paroxysmal throes. When lavas refrigerate through the whole stratum, and thus rest upon an ancient or previous formation, they form dams or obstructions which divert the stream of lava from above, unless this obstruction is lifted, broken up, tilted, or overflowed by fresh supplies of lava. Down the steep sides of the mountain such obstructions occur more rarely; consequently, after a few days of widespreading over these high regions, and when the superficial hardening process is completed, the lava ceases to reach the surface, either at the fountain or down the sides of the mountain, but is confined to channels, mostly covered with fresh solidified lavas, where it finds a free and rapid passage to the plains below. Here the movement is slow, the obstructions more numerous, and the force to overcome them less potent. This accounts for the spreading laterally, the upliftings, the tiltings, the vertical gushings, the submergings, the fractures, pits, dams, ridges, little cones, and the ten thousand irregularities which *diversify the ever-changing surface of lava-streams,* while the fusion is struggling to work its passage, or to keep open its ever-choking *channels below, i.e., between its own crust and the former surface of the* earth. I have seen a dome, some 300 feet in diameter at its base, raised *100 feet high, and split from the summit in numerous radii, through which* the red and viscid fusion was seen; and I have mounted to the top of such a dome, *in this state,* thrust my pole into the liquid fire, and measured the thickness of its shell, which was from two to five feet. Now this dome, which may be represented by an egg standing on its larger end, was full of liquid lava, visible and tangible, through the cracked shell of which you could thrust a pole to great depth into the fusion. This dome, with thousands of similar ones of various sizes, was formed simply by hydrostatic pressure. This force, and that of vapours formed by the combustion of vast quantities of trees and other vegetable matter submerged by the mineral river, produce the marvellous and mighty effects seen on the surface of the lava-streams."

Again, the quieter, but not less important, effects of *mud-volcanoes* and *solfataras* are well described in the following extract from Sir George Mackenzie's *Travels in Iceland*:—"At the foot of the Sulphur Mountain, about three miles from Krisuvik, was a small bank, composed chiefly of white clay and some sulphur, from all parts of which steam issued. Ascending it, we got upon a ridge immediately above a deep hollow, from which a profusion of vapour arose, and heard a confused noise of boiling and splashing, joined to the roaring of steam escaping from narrow crevices in the rock. This hollow, together with the whole side of the mountain opposite as far as we could see, was covered with sulphur and clay, chiefly of a white or yellowish colour, and forming a crust from a quarter of an inch to several inches in thickness. Walking over this soft and steaming surface we found to be very hazardous. The chance of the crust of sulphur

breaking or the clay sinking with us was great, and we were several times in danger of being much scalded. From whatever spot the sulphur is removed steam instantly escapes; and in many places the sulphur was so hot that we could scarcely handle it. From the smell, I perceived that the steam was mixed with a small quantity of sulphuretted hydrogen gas. When the thermometer was sunk a few inches into the clay, it rose generally to within a few degrees of the boiling point. At the bottom of this hollow we found a caldron of boiling mud, about 15 feet in diameter, similar to that on the top of the mountain, which we had seen the evening before; but this boiled with much more vehemence. We went within a few yards of it, the wind happening to be remarkably favourable for viewing every part of this singular scene. The mud was in constant agitation, and often thrown up to the height of six or eight feet. Near this spot was an irregular space filled with water boiling briskly; and at the foot of the hill steam rushed with great force from among the loose fragments of rocks."]

Physical Aspects.

128. Although volcanic rocks are unknown in the British Islands, they occur extensively in many regions of the globe; geographers enumerating between 200 and 300 active or partially-active craters of eruption. In Europe there are three well-known centres of igneous action—viz., that of Italy, to which Etna and Vesuvius belong; that of Iceland or Hecla; and that of the Azores. In Asia there are ample evidences of igneous activity along the borders of the Levant, the Caspian, and the Red Sea; in the Indian Ocean; throughout the whole of the Indian Archipelago; and northward through the Philippine, Japan, and Aleutian islands. In the Antarctic Ocean several cones of active eruption were discovered by our voyagers in 1841; and in the Pacific, the islands of New Zealand, the Sandwich, and other groups, are for the most part the results of volcanic action. In the Atlantic, the Canaries, Cape de Verd, Ascension, and other islands skirting the western coast of Africa, are well-known seats of igneous action; while in the West Indies, and along the entire continent of America, from the islands of Terra del Fuego (Land of Fire), northward through the Andes and Rocky Mountains, are numerous volcanic vents in a state of greater or less activity. In these centres of igneous action many of the volcanoes seem to be *extinct;* some are merely smouldering or *dormant;* while others are incessantly *active*, either ejecting rocky matter from their craters, or rending the surrounding country by earthquake convulsions. On the geographical features of existing volcanoes, however, we need not here enter, as these will receive more detailed description when we come to treat of the Post-tertiary or Recent Accumulations.

Industrial Products.

129. In an industrial point of view, volcanic products are of considerable importance. As already mentioned, all, or nearly all, the *sulphur* of commerce is derived from volcanic districts—Sicily alone yielding upwards of 80,000 tons a-year. Several of the *lavas* make a light and durable building-stone; and others are cut and polished for ornamental purposes like marble. *Pumice* has been long used as a polishing or rubbing stone, and for that purpose many hundreds of tons are annually collected at a rate varying from £6 to £10 a-ton according to quality. *Obsidian* was used by the ancients for looking-glasses; and the natives of various regions have used it, as our forefathers used flints, for knives, arrow-heads, hatchets, and other cutting instruments. *Puozzolana* (which by some is regarded as an altered felspathic tufa) has been long employed in the manufacture of Roman or hydraulic cement, a use to which the analogous *trass* of the Rhine has also been applied. Besides sulphur, *sal-ammoniac* and *borax* may be regarded as volcanic products—the former being found in most igneous districts, and the latter being produced by hot springs, like the Lagoons of Tuscany, which yield more than 1000 tons annually of crystallised boracic acid. Like the trap-rocks, many of the older lavas yield *agates*, *chalcedony*, *leucite*, *spinelle*, *olivine*, and other precious minerals; while some of them are *metalliferous*, and contain, though seldom in available quantities, iron, titanium, manganese, copper, mercury, and gold.

NOTE, RECAPITULATORY AND EXPLANATORY.

130. The products described in the preceding chapter constitute one of the great divisions into which the rock-masses of the globe have been arranged. Though containing no fossil record (except in a few rare instances to be afterwards noticed) of the kind of plants and animals which have successively peopled the earth—and in this respect of less value in enabling us to decipher its history—they are still important monuments of past change; monuments in which we can trace the features of the world's former surface—its alternations of hill and valley, of sea and land, and of many of those external conditions which give character and colouring to organic life. In this respect they are of

prime importance; and it is only by studying their relations to, and the manner in which they have affected the stratified rocks, that we can ever hope to solve many of the most intricate problems in geology. Their arrangement into GRANITIC, TRAPPEAN, and VOLCANIC, though partaking more of a mineralogical than of a geological distinction, is not without its value, so long as the student remembers that granite, though the deepest-seated igneous rock, may also be associated with strata of all ages, and that trap-rock, though most abundantly developed during the secondary period, may also be found in connection with strata of the earliest epochs. Bearing in mind these facts, and remembering also how similar many of these rocks are in mineral composition, and that they all occur in connection with the stratified formations—as *disrupting*, *overlying*, or *interstratified* masses—the student will readily perceive that it is chiefly in their mineral and mechanical bearings that he has to deal with them. Thus, the granitic masses are never scoriaceous and cellular like recent volcanic rocks, nor are they ever earthy and amygdaloidal, like many of the trappean compounds. The trap-rocks, as a whole, are less felspathic than the granites and porphyries, and exhibit a greater tendency to structural arrangement than either granitic or volcanic products; while the volcanic are decidedly more cellular, slag-like, and vitreous, than either the granites or traps.

131. Touching the structural development of the trap-rocks (the spherical, columnar, tabular, and other arrangements), it may be here briefly remarked that they all seem to be the results of one process—namely, that of cooling or crystallisation on the large scale. The sphere or radiated globule appears to be the primary form, and we can demonstrate by experiment that such incipient globules will arrange themselves in columns more or less distinct, in tabular masses, or in distinct spherical concretions, according to the pressure and mode of cooling to which the molten mass has been subjected. Take, for example, a mass of putty pellets, and subject them to varying degrees of lateral and vertical pressure, and it will be found on removing the pressure that they have arranged themselves in columnar and jointed order, precisely similar to the five and six sided basaltic columns of the Giant's Causeway. It matters not whether the interfering force be pressure from without, unequal contraction of the mass, or expansion from within, the result will be the same; and just in proportion as these have been applied, so will there arise columns, tabular masses, or spherical concretions. It is a common error to suppose that the columnar structure should be

always perpendicular or nearly so; the fact being, that basaltic columns are found lying in every direction—vertical, inclined, and horizontal. The general arrangement of the columns is at right angles to the cooling surface; hence the horizontal columns of basaltic dykes—these ranging at right angles to the cooling walls of the strata through which the molten mass has been ejected.

132. Arranging the igneous or pyrogenous rocks under the great divisions of Granitic, Trappean, and Volcanic, we have under each the following varieties, with which the geological student should early endeavour to make himself familiar:—

GRANITIC.—Granite proper, graphic granite; porphyritic granite, syenite, syenitic granite, hypersthenic granite; protogine; pegmatite, hornblende rock, hypersthene rock; primitive or syenitic greenstone; serpentine; and the various felspathic compounds known as granitic porphyries. The accidental minerals or crystals occurring most abundantly in granitic rocks are—glassy felspar, rock-crystal, schorl, tourmaline, beryl, garnet, apatite, chlorite, steatite, and asbestos.

TRAPPEAN.—Basalt, clinkstone, basaltic-clinkstone (diorite), greenstone (dolerite), greenstone porphyry; compact felspar or felstone, felspar porphyry; hornstone, pitchstone, pitchstone porphyry; claystone, claystone porphyry; amygdaloid, trap-tuff, wackè, and trap-breccia. The accidental and imbedded minerals are—hornblende, augite, olivine, agate, chalcedony, jasper, and a numerous class having a fibrous, radiated aspect, known as zeolites, mesotypes, prehnites, &c.

VOLCANIC.—Lava, basaltic lava, trachyte or greystone; obsidian, pumice, pearlstone; tufa; scoriæ, ashes, volcanic sand, dust; puozzolana, trass; palagonite and siliceous sinter from hot springs; sulphur, boracic acid, carbonic acid, and sulphuretted hydrogen.

Theories of Volcanic Action.

133. Respecting the origin of the pyrogenous rocks, or rather the cause of igneous action with all its attendant phenomena of volcanoes, earthquakes, and other subterranean movements, geologists are by no means agreed. The two most prevalent hypotheses are what have been termed the *chemical* and *mechanical*—the former endeavouring to account for the phenomena on chemical principles, the latter ascribing them to some great source of heat within the interior of our planet. By the latter hypothesis it is assumed, chiefly on the ground of increasing temperature as we descend into the crust, that the interior of the globe is in a state of high incandescence or molten fluidity; that the cooled or rocky exterior is of inconsiderable and varying thickness; and that this crust is extensively cavernous, rent and fissured—primarily by unequal contraction from cooling, and subsequently by subterranean agitations. As this cooling process must be still going on, however slowly, the least contraction of the crust—even to

the fraction of an inch—would be sufficient to squirt out molten rock-matter from a hundred pores or craters. Water also finds its way through the fissures of the crust, and, coming in contact with the heated mass within, generates steam and other gases, and these, exploding and struggling to expand, produce earthquakes and agitations, which are rendered more perceptible by the cavernous and fissured condition of the crust, and the yielding material upon which it rests—the thin rocky film, undulating and rending like a sheet of ice on the surface of agitated water. Occasionally the heated vapours make their way through fissures and other openings, as gaseous exhalations, or as hot springs and jets of steam and water, carrying with them various sublimations and solutions of the rocks through which they pass. On the other hand, when the expansive forces within become so powerful as to break through the earth's crust, discharges of melted rock-matter (lava), red-hot stones, ashes, dust, steam, and other vapours follow; and repetitions of such discharges at longer or shorter intervals gradually form volcanic cones; and lines and centres of such activity produce, in course of ages, mountain groups and ranges. It does not follow, however, that volcanic discharges must always take place at the point where the greatest external contraction or internal pressure is exerted; on the contrary, the molten mass will obey the law of hydrostatic pressure, and be propelled to whatever craters or fissures may already exist. This so-called "mechanical" theory of central heat is further supported by the occurrence of igneous phenomena in every region of the globe, and by the fact that most volcanic centres are in intimate connection with each other—a commotion in one district being usually accompanied by similar disturbances in another. It is sometimes objected to this hypothesis, that if all the igneous rocks proceed from a common source, there ought to be a greater uniformity among them in composition and aspect; but, on the whole, there is really a great similarity in composition, and there is nothing in their differences that may not be accounted for by pressure, rapidity or slowness of cooling, fusion and re-fusion, and commminglement with the melted matter of the stratified rocks through which the eruptions take place.

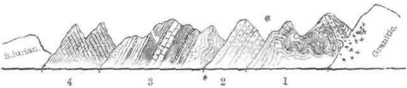
134. Turning now to the chemical hypothesis, we find that while it offers no opinion as to the original igneous condition of the globe, it endeavours to account for volcanic phenomena by appeals to chemical actions and reactions now taking place among the materials composing the rocky crust. The metallic bases of the alkalies and earth, as potassium, sodium, calcium, &c., the

moment they come in contact with water, are decomposed with an evolution of intense heat; and this heat, it is contended, is sufficient to fuse rocks, convert water into steam, and give rise, by mutual decompositions, to escapes of carbonic acid, sulphuretted hydrogen, and other gases. This hypothesis proceeds, of course, upon the supposition that such metallic bases exist within the globe, where water, finding its way to them through chinks and fissures, unites and causes the phenomena in question; and it also presumes their universality and abundance to account for the prevalence of igneous action in all time, past as well as present. This theory offers no opinion as to the gradual cooling of the globe from a state of fusion, but strives to elicit the continuous operation of natural laws, rather than appeal to original conditions of which we know so little by direct induction. Of the two hypotheses it is certainly the more philosophical, as admitting in nature a *perpetual* power of renewal of the same phenomena from her own inherent materials, instead of appealing to an *exhaustible source*, such as an original igneous state of the globe necessarily implies; but as yet our knowledge of the earth's crust at great depths is too limited; we know too little of the chemical and magnetic operations which may be going forward among its rocks; and we are too slenderly acquainted with the transpositions which may take place among its metals and minerals, to accept the chemical theory as adequate to account for the magnitude of the phenomena in question. It is true there occurs nothing among the products of volcanoes at variance with its assumptions; but the magnitude, the universality, and the apparent greater extent of igneous action in earlier geological times, would seem to point to a more stable and uniform source—that source, according to the general geological belief, being the original interior molten mass of the globe, around which time and external conditions have gathered a cooled and solid crust of heterogeneous rock-material.

135. Another point connected with the history of volcanoes—and one which has recently given rise to much discussion—is that which involves the so-called theories of "craters of elevation" and "craters of eruption." Till of late years volcanic cones and craters, whether large or small, were generally regarded as the results of eruptions from within—the ejected matters gradually accumulating in form more or less conical round the crater or outlet of eruption. This view has been opposed chiefly by Humboldt, Von Buch, Eliè de Beaumont and Dufrénoy, who denied that volcanic mountains have been

formed by the accumulation of erupted matters, and attribute them solely to a sudden "bubble-shaped expansion or swelling-up" of the earth's crust — the bubble sometimes bursting at top, and then bearing its broken sides tilted up around a hollow (elevation crater). On the other hand, Lyell, Prevost, Scrope, and many others, contend for the "eruptive-crater" theory, and maintain that the characters of all volcanic mountains and rocks are simply and naturally to be accounted for by their eruptive origin—the lavas and fragmentary matters accumulating round the vent in forms determined in a great degree by the more or less imperfect fluidity of the former, the less fluid (trachytic lava) cooling in domes and ledges right over and around the crater, the more fluid (basaltic lava) passing down moderate declivities, and spreading to great distances. Like most other disputed points in Geology, there is much of both theories that must be accepted to account fully and fairly not only for isolated cones (which are in the main composed of erupted matters), but also for mountain-chains whose chief features and lines of direction are evidently produced by upheaval and other internal movements of the earth's solid crust. In fact, upheaval and eruption are ever concomitant causes, or rather they are *varied expressions of the same force*, and to attempt to dissociate them because one cone is chiefly composed of "erupted" matter, and another of "upheaved" strata, is certainly not the most approved mode of arriving at the "true causes" of geological phenomena.

136. The limited extent of an elementary work prevents further discussion of these interesting topics; but the student may rest assured that there are few departments more worthy of his attention, and none at present less pursued, than the study of the igneous rocks, and the causes which have led to their production. Should he be inclined to follow the subject more in detail, he cannot avail himself of higher help than the *Physical, Chemical, and Geological Researches* of Professor Bischoff of Bonn, the *Treatise on Volcanoes* by Dr Daubeny of Oxford, Mr Poullet Scrope's *Geology and Extinct Volcanoes of Central France*, and Mr Darwin's *Geological Observations on Volcanic Islands*. Touching the special subject of the "eruption" and "elevation" theories, he may consult the admirable paper of Sir Charles Lyell in the *Royal Society's Transactions* for 1859, and Mr Scrope's amply illustrated article in the fifteenth volume of the *Geological Society's Journal*. For a description of the mere rock-products, M'Culloch's *Classification of Rocks*, and any modern treatise on mineralogy, may be consulted with advantage.



VIII.

THE METAMORPHIC OR HYPOZOIC SYSTEM:

EMBRACING—1, THE GNEISS; 2, QUARTZ-ROCK; 3, MICA-SCHIST; AND, 4, CLAY-SLATE GROUPS.

137. WITHOUT adhering to the common belief that granite forms the floor or basis on which all the stratified systems repose, it may at least be confidently asserted that granitic compounds upheave and break through the lowest known strata, and in this sense are certainly under-formed or deeper-seated than any other rocks with which we are yet acquainted. Whether this arises from an original igneous condition which has imparted to these rocks a uniformity of character, or whether it be that all deep-seated rocks, by heat and pressure, have been made to assume a similarity of aspect, geology is yet unable to determine, and must *rest satisfied in the mean time with a simple statement of the facts.* It is on this ground that Sir Charles Lyell has proposed the term *Hypogene*, or under-formed (*hypo*, under, and *ginomai*, I am formed), to embrace all the lower crystalline rocks; but as granite, in its eruptive character, is altogether a different rock from gneiss, mica-schist, or crystalline limestone, which are never eruptive, the term appears inapplicable, and if to be used at all, must be restricted to granitic compounds, whether eruptive or of doubtful origin. It may be quite true that gneiss and mica-schist, if subjected to heat and pressure, would, in process of time, become undistinguishable from some varieties of granite; and that

sandstones and shales, if subjected to the same agencies, would assume a crystalline aspect. This, however, is merely saying that mechanically-sedimentary rocks have been converted *by heat* into crystalline compounds; and that crystalline compounds have been changed by the same process into pyrogenous masses. We must draw a line of distinction somewhere—and whether granite may have once been crystalline schists or crystalline schists sedimentary strata, we have now the facts presented to our observation, that eruptive granitic rocks are clearly separable as a group from the crystalline schists that repose upon them, in stratiform arrangements less or more perceptible. Assuming, then, that the granitic rocks already described constitute the true *hypogene* group, that they immediately underlie, and are intimately associated with the lowest stratified schists, we obtain a starting-point in the crust, from which to commence an intelligible description of the systems that follow.

138. The crystalline schists—gneiss, mica-schist, &c.—are frequently grouped as the *Non-fossiliferous system*, from their containing no remains of plants or animals, so far as the geologists have been enabled to discover. For the same reason they have been termed *Azoic*, or destitute of life (*a*, without, and *zoè*, life), in contradistinction to the upper systems, which are all less or more fossiliferous. As this distinction, however, is founded solely on negative evidence, and as fossils may yet be discovered in some portion of these rocks, which in many tracts are evidently metamorphosed silurian and cambrian strata, it is thought better to employ the term *Hypozoic* (*hypo*, under, and *zoè*, life), which merely indicates that the system lies under all those that are known to be unmistakably fossiliferous. The name *Metamorphic* refers, on the other hand, to its mineral characteristics, and implies that the original structure and texture of its rocks have undergone some internal change or metamorphosis. At present these rocks are all less or more crystalline; their lines of stratification are often obliterated, or but faintly perceptible, and their whole aspect is very different from what is usually ascribed to rocks originally deposited in water. This change may have been brought about (as will be seen in the recapitulation) by the application of external heat and pressure, or it may be the result of some peculiar chemical action among the particles of which the rocks are composed. In whatever way the metamorphosis has been effected, we see clearly that a change has taken place in the original sedimentary character of the strata, and that matter which

at first consisted of water-worn debris—as silt, clay, and sand—has now been converted into hard, shining, and crystalline rocks. It must be remembered, however, that though mineral metamorphism is peculiarly the characteristic of this set of strata, it is by no means confined to gneiss and mica-schist; for, as we shall afterwards see, many sandstones of the latter systems have been converted into quartzite or quartz-rock, many shales into jaspery-hornstones, earthy limestones into sparkling saccharoid marbles, and soft bituminous coals into anthracite and graphite. Wherever heat, pressure, and chemical agency are present in any notable degree, there will mineral metamorphism manifest itself—consolidating, compacting, and altering the molecular arrangement of all sedimentary strata, and that in proportion to the intensity of the agencies at work, and the length of time these agencies have been in operation.

139. The question naturally arises, If gneiss and mica-schist be indeed metamorphosed aqueous strata, may they not have been originally fossiliferous—the fossils being now obliterated by the crystalline metamorphosis? All that can be said in reply, in the present state of our knowledge, is simply that no decided organic remains have yet been detected in these schists; and, judging from the obscure traces of fossils in altered secondary rocks, there is little hope of ever obtaining evidence of organic life in the more ancient and highly crystalline strata. The effect of such a discovery would, no doubt, greatly modify our views of Life and development, by carrying us immeasurably farther into the past, but this would be all; it would overturn no truth already established, nor interfere with our schemes of classification so long as we regard the rocks of which we are now treating simply as "metamorphic," throwing aside all other views which imply either the probable presence or absolute absence of organic remains. It is in this provisional view that we shall now treat them, frankly admitting that geology is not yet in a position to speak dogmatically on the subject.

I.—GNEISS, QUARTZ-ROCK, AND MICA-SCHIST.

140. We arrange these groups under one head, for this reason, that though there is often a sufficient mineral distinction between them when viewed on a large scale, there is, after all, very little difference in their geological character and history. In whatever state of aggregation the particles of *Gneiss* may have been when

originally deposited, we now know that it is a hard, tough, crystalline rock, exhibiting curved and flexured lines of stratification, and composed in the main of quartz, felspar, mica, and hornblende. Mineralogically speaking, it differs from the granitic rocks with which it is associated chiefly in this, that while the crystals of quartz, felspar, &c., are distinct and entire in granite, in gneiss they are broken, indistinct, and confusedly aggregated. There is also this essential distinction, even where the mineral aspects of the two rocks are most alike, that the gneiss never sends out dykes and veins, like the granite, into contiguous strata; nor does it ever assume the tabular or sub-columnar structure so frequent in granite—a structure peculiar to rocks which are the products of cooling and consolidation from a state of igneous fusion. In the most granitoid masses of gneiss, the stratified disposition is never wholly obliterated; hence their *fissility* in one direction as compared with the indeterminate and hackly *fracture* of the true igneous granites. *Quartz-rock*, which consists of finely-granular quartz, with occasionally conglomerate-looking bands, and beds intermingled with flakes of mica, scarcely holds a determinate place among the primary strata; though in the Scottish Highlands its greatest development is clearly intermediate between the gneiss and mica-schist. It is in general less flexured and foliated than the gneiss, hence its stratification is more apparent; and hence also its value to the geologist in enabling him to determine lines of strike and dip in contorted primary regions. What has been affirmed of the sedimentary origin of gneiss is much more apparent in *Mica-schist*, which is often finely-laminated and distinct in its lines of stratification. This distinction arises, in all likelihood, from the greater attrition the original particles have undergone, and from the greater proportion of mica entering into its composition in the form of fragmented flakes or scales. There is, however, a great similarity between the three sets of rocks—beds and bands of gneiss interlacing and alternating with beds of quartz-rock, bands of quartzitic rock occurring indiscriminately among gneiss and mica-schists, and gneissose rocks frequently becoming so micaceous in their composition as to be undistinguishable from true micacite. On the whole, the three groups may be said to be composed essentially of felspar, quartz, mica, talc, hornblende, and chlorite—these ingredients having been deposited in beds and layers of silt, clay, sand, and the like, but afterwards consolidated and altered in their internal structure so as to have become highly crystalline, and very similar in their general aspect to the granites

from which, by the processes of waste and disintegration, they were originally derived.

141. Though it is often difficult to draw lines of distinction between these groups, and to say where the one ends or the other begins, it may be received as a general truth that gneiss, or rocks of a gneissic character, occupy the lowest position in the metamorphic system as developed in the British Islands; that these are succeeded by a zone of quartzitic compounds; and these again by mica-schists, which graduate imperceptibly into the chloritic and argillaceous slates that cap the series, thus:—

> CLAY-SLATE—chloritic and argillaceous slates.
> MICA-SCHIST—micaceous, talcose, and chloritic schists.
> QUARTZ-ROCK—quartzitic compounds, generally thick-bedded.
> GNEISS—*gneiss-rock and granitoid schists.*

Such is the order of succession we would indicate, and so it occurs on the great scale in the most typical of all metamorphic regions, the Highlands of Scotland. There is this misconception, however, to be guarded against, namely, that the terms gneiss, quartz-rock, and mica-schist, being used to designate not only stratified groups, but also certain peculiar rocks, the student is apt to imagine that the system is composed solely of these rock-compounds. Nothing could be more erroneous, inasmuch as both gneiss and mica-schist occur interstratified with quartz-rock, crystalline limestone, serpentinous bands, talc-schist, chloritic-schist, and other so-called primary strata. We use the terms "Gneiss" and "Mica-schist" just as we speak of the Old Red Sandstone and Coal-measures—taking the most distinctive rock as a name for the series, without intending in the least to convey the impression that either sandstones or coals are the only rocks in their respective formations. In the metamorphic system more than in any other is it difficult to ascertain any definite order of succession among the strata—the whole being so contorted and broken up by granitic intrusions, and having undergone such a change in mineral character, that one rock frequently passes by insensible gradations into another within the space of a few hundred feet. Under these circumstances, it is perhaps better simply to enumerate the more prevalent rocks in the system—premising that while the great grouping may remain as already indicated, the individual strata often alternate and capriciously intermingle with each other:—

Gneiss—an aggregate of quartz, felspar, and mica, occasionally garnetiferous.

Porphyritic Gneiss—the same as above, with large irregular macles of felspar or quartz.

Syenitic Gneiss—of quartz, felspar, and hornblende.
Hornblende schist—a slaty rock, chiefly of hornblende, with felspar or quartz.
Quartz-rock and Quartzite—granular aggregates of quartz with occasional flakes of mica—the quartzites being indurated quartzose rocks of a more arenaceous aspect than quartz-rock proper.
Mica-schist—a fissile or laminated aggregate of mica and quartz, with occasional crystals of hornblende and garnet.
Talc-schist—of talc and quartz, and differs only in this respect from mica-schist.
Chlorite-schist—a greenish slaty rock of chlorite and quartz; often passing into mica-schist and clay-slate.
Actynolite-schist—a slaty foliated rock, chiefly of actynolite, with some admixture of felspar, quartz, or mica.
Primary limestone—highly crystalline marbles, often containing veins and flakes of serpentine, chlorite, steatite, and the like, with occasional crystals of sahlite, and other accidental minerals.

When the above are massive and compact, they are spoken of as *rocks;* when laminated and fissile, they are termed *schists*, and by this name it were advisable to designate all the truly primary metamorphic strata, with the exception of clay-slate, which, as will be seen, often owes its fissility to another cause than bedding or deposition. The term *foliation* (*folium*, a leaf) is employed to express that irregular leafy-like crumpling which occurs so prevalently among these schists—a structure for which, as well as for slaty-cleavage, numerous hypotheses have been advanced; but which, as the student will shortly find, remains in a great measure an unsolved problem.

142. It has been stated that the strata of the metamorphic system often capriciously alternate and intermingle; and one cannot pass over a section of any extent, such as is presented in the glens or along the coasts of the Scottish Highlands, without perceiving the truth of this remark. We may pass, for instance, for many hundred yards along rocks of a mixed gneissic character; then meet with several bands of grey crystalline limestone; find these succeeded by more fissile gneiss, with bold independent bands of quartz-rock; meet again with beds of gneiss which pass imperceptibly into mica-schists; next discover beds of crystalline fissile limestone, succeeded by chloritic schists; and ultimately find that these chloritic bands graduate by degrees into the true fissile clay-slates that close the system. If the district be very much contorted and broken up by igneous eruptions, then we may have dykes and veins of granite, with the gneiss in contact rendered porphyritic and hornblendic; or may have dykes of hornblende-rock, greenstone, and porphyry, causing irregular contortions and foliations among the gneiss and mica-schists, in which case we shall find veins of serpentine and glassy quartz, numerous

garnetiferous bands, the limestones rendered chloritic, micaceous, and serpentinous, together with superinduced actynolites, talc-schists, veins of asbestos, and not unfrequently exhibitions of metallic ores.

Physical Aspects.

143. The gneiss and mica-schist groups are widely distributed, being found flanking less or more all the principal mountain-chains in the world. They occur in the Highlands and Islands of Scotland, in the north and south of Ireland, in Brittany, in the Bohemian and Saxon ridges, along the flanks of the Pyrenees and Alps, in the Scandinavian, Carpathian, and Oural chains, largely in the Caucasian, Altai, and Himalayan ranges of Asia, in the Andes and Brazilian sierras of South America, and in the Cordilleras of Mexico, the Rocky Mountains, and along the entire length of the Alleghanies in North America. Though thus flanking and forming portions of most of the older mountain-chains, the primary strata do not occupy wide areas, but are tilted up at high angles, and compressed into a comparatively narrow space, producing rugged and abrupt scenery, less bald and bleak than granite, but wilder and more irregular than that of later formations. On the whole, the physical aspects of primary districts may be described as rugged, irregular, and barren. Thrown into lofty mountains by the granite, and often into abrupt and vertical positions, it is chiefly among gneiss and mica-schists that those deep glens and abrupt precipices occur which give to Highland scenery its well-known wild and picturesque effect. In lower and sheltered situations, some of the softer mica-schists decompose into a not unfertile soil, and some of the finest timber in the world is grown on rocks of that formation.

144. As already mentioned, the igneous rocks associated with the gneiss and mica-schists are chiefly granitic—these upheaving, breaking through, indurating, and contorting them in a very complicated manner. Later igneous rocks — as hornblende, hypersthene, porphyry, syenitic-greenstone, and serpentine—are also found traversing those groups in the form of dykes and protruding masses, and occasionally still more recent effusions of trap are found passing through, not only the gneiss and mica-schists, but their associated dykes and veins of granite and porphyry. On the whole, granite, syenite, porphyry, and serpentine are the great contemporaneous igneous products, and are so peculiar in

their crystalline aggregations, that there is in general little difficulty in distinguishing them from the igneous rocks of later epochs.

Industrial Products.

145. The industrial or economic products derived from the gneiss and mica-schists are, lithologically speaking, by no means numerous. The limestones, from their highly saccharoid texture, and mottled and veined appearances, yield valuable *marbles;* and are also quarried for mortar and farming purposes. The *serpentines,* when found in solid masses, like those of Portsoy, Lizard Point, and Connemara, produce a very elegant material for internal decoration, or for minor ornaments, as vases, jars, pedestals, paper-weights, &c. Neither gneiss, mica-schist, nor talc-schist yield a very elegant building-stone, yet in several districts in the north of Scotland they are so employed, while the harder kinds of gneiss have been successfully raised in huge blocks for pier and breakwater purposes. *Quartz-rock,* where sufficiently pure, as in Banffshire, Sutherlandshire, &c., is extensively quarried for the potteries, the large blocks being used for grinding the calcined flints, without deteriorating the purity of the frit. *Potstone,* or the *lapis ollaris* of the ancients, is a common product of the system, and in some countries, as the north of Italy, is still manufactured into pots and vases. *Amianthus* or flexible asbestos, found in veins traversing metamorphic strata, is still occasionally used in the manufacture of fireproof cloth, for lamp-wicks, and also for gas-grates, the fibres remaining red-hot without being destroyed. It has also been tried in the fabrication of fireproof paper, but not, so far as we have heard, with anything like important success. One of the most valuable substances derived from the system is *graphite* or *plumbago* (96 of carbon and 4 of iron), so largely employed for writing-pencils, for polishing, for crucibles, and similar uses; and which is evidently a metamorphosed *anthracite,* in all likelihood of vegetable origin, though a purely chemical elaboration has been ingeniously suggested for the occurrence of carbons and hydro-carbons in these primitive formations. Among the minor products may be mentioned *steatite* or soapstone, *whet-slate, umber,* and plastic carbonate of magnesia, or *meerschaum.* The diamond, beryl, rock-crystal, garnet, zircon, and other *precious stones,* are found in the system, either imbedded in the strata themselves, or in the veins that traverse them. These veins are also the repositories of many of the most important

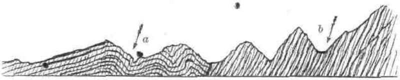
metallic ores, as those of tin, copper, zinc, cobalt, iron, molybdenum, and less abundantly native silver and gold.

II.—CLAY-SLATE GROUP.

146. Whatever obscurity may attach to the sedimentary origin of gneiss and mica-schist, there can be no doubt as to the true aqueous character of the clay-slates and their associated strata. The clay-slate group, so familiarly known by the bluish, greenish, and purplish roofing-slates of our towns, presents a vast thickness of fine-grained, fissile, argillaceous rock, of considerable hardness, and if not of a crystalline, at least of a glistening aspect. It seems to have been originally deposited as a fine clay or silt, and then to have undergone metamorphism in a less degree than the underlying mica-schists and gneiss rocks. The prevalent colours of slate are black, green, bluish, purplish, and mottled. Some varieties are hard and splintery, others soft and perishable. The texture, though generally close and fine-grained, is not unfrequently gritty and arenaceous, and passes into a sort of flaggy sandstone. The imbedded minerals are few; these being chiefly cubic iron-pyrites, chert or siliceous concretions, crystals of hornblende, augite, and chiastolite, a mineral occurring in long slender prisms, which cross and lie over each other in the mass of slate like the Greek letter χ (*chiastos*, crossed or marked with the letter χ, and *lithos*, a stone). Such are the lithological characters of the clay-slate proper; but it must be noted that chlorite slate, cherty grits, crystalline limestones, and not unfrequently bands of quartz-rock and magnetite (magnetic iron-ore), are associated with the group, making in some eruptive regions a very complex suite of strata.

147. If the gneiss and mica-schist were derived from the disintegration of granitic and earlier rocks, clay-slate seems to have been derived from the same source, and also from the further and finer disintegration of the gneiss and mica-schists. In the clay-slates the quartz and mica of the original rocks appear in minute grains and flakes, and the clay of the felspar appears as impalpable sediment, destitute of the potash and soda which entered into its crystallised condition in granite. All this bespeaks the long-continued action of atmosphere and water—atmosphere and water to waste and wear down, and rivers to transport the material to some tranquil sea of deposit. In course of time the soft sediment becomes consolidated; heat or chemical agency subsequently

changes its texture, and renders it hard and crystalline; and a still further alteration produces that peculiar structure in many clay-slates known by the name of *cleavage*. What renders slate so peculiarly valuable, is its quality of being cleft or split into



Slaty Cleavage—*a*, Transverse: *b*, Coincident.

thin plates or layers; and this splitting takes place, not always parallel to the lines of stratification as in the flagstones used for pavement, but in a direction right through the beds, and often almost at right angles to them, as indicated by the arrows *a* and *b* in the preceding diagram. This cleavage-structure is occasionally observed in other rocks of an argillaceous or clayey nature, but more especially in clay-slate; and its origin is still a matter of doubt among geologists. "Pervading high temperature," says Professor Phillips, "is generally admitted as the efficient cause of the *metamorphism* of gneiss and mica-schist; but clay-slate is thought by many modern writers to have acquired its *lamination* mainly through pressure." On the other hand, its extreme regularity and resemblance to certain kinds of crystallisation, have suggested the hypothesis that it may have arisen from chemical or magnetic forces acting upon the clayey mass while in process of solidification—a supposition greatly strengthened by the fact that a similar structure has been produced in masses of clay by the artificial application of these forces. Of this, however, as well as of the analogous phenomenon of *foliation*, when we come to treat of the theories of metamorphism in the note recapitulatory to the present chapter.

Physical Aspects.

148. Being intimately associated with the gneiss and mica-schist groups, the clay-slate partakes of many of the upheavals and disruptions which have affected these strata. Though less crystalline in its texture, and not so much broken up by igneous intrusions, its beds are in many instances curiously bent and contorted, and generally rest at high angles on the flanks of our oldest mountain-chains. They are found along with mica-schist

and gneiss in almost all the regions already enumerated, and form valuable deposits in the Highlands of Scotland, in Cumberland, and in Wales. The scenery of clay-slate districts is often wild and picturesque, its beds of unequal hardness presenting a peculiarly peaked and splintery outline; but their high elevation and cold clayey soils render them sterile and unproductive.

Industrial Products.

149. The industrial applications of clay-slate are numerous and well known. The hard fissile varieties have long yielded a most valuable roofing-material; the finer sorts are used for writing-slates and slate-pencils; and the thicker-bedded kinds are now largely employed as an ornamental stone for vases, tables, chimney-slabs, mosaic pavement, cisterns, and other architectural purposes. From the facility with which it can be shaped and transported, the fine clean surface it takes, as well as from its comparative lightness and durability, it is only matter of surprise that it has not been much more extensively used for internal fittings. The clay-slate in many districts, like those of Wales, Cornwall, and Cumberland, is abundantly traversed by metalliferous veins, and from these are obtained ores of tin, copper, lead, silver, and not unfrequently gold.

NOTE, RECAPITULATORY AND EXPLANATORY.

150. The system described in the preceding chapter consists of four principal groups—Gneiss, Quartz-rock, Mica-schist, and Clay-slate. The rocks composing these groups are less or more indurated and crystalline, have their lines of stratification indistinct, and often altogether obliterated, and, as sedimentary strata, have evidently undergone some peculiar change in their internal structure. This change, or metamorphism, whether produced by heat, pressure, or chemical agency, has conferred upon them the term of *Metamorphic rocks;* and by this designation they are now generally known among geologists. As strata, they are the deepest or lowest in the crust of the earth, and are therefore regarded as *Primary* or first-formed. They are also known as *Non-fossiliferous, Azoic,* or *Hypozoic* strata, from the

fact that no distinct traces of plants or animals have yet been discovered in any part of the system. The terms metamorphic, primary, hypozoic, and non-fossiliferous, may be held as synonymous—the student ever bearing in mind that the nomenclature of geology is at best but provisional or temporary, and must give way to new facts and the progress of discovery. As a general rule, the gneiss group lies beneath the mica-schist, and the mica-schist beneath the clay-slate; but there are frequent alternations of the rocks and schists composing the system, and these alternations are often rendered more complicated by the contortions and displacements produced by the intrusion of granitic outbursts. Though mineralogists have given to the rocks composing the system different names—as gneiss, syenitic-gneiss, hornblende-rock, hornblende-schist, mica-schist, talc-schist, stea-schist, chlorite-schist, &c.—it must be admitted that there are often a great similarity and frequent gradations among them. Whether this arises from their being immediately derived from the disintegration of older granitic rocks, or from the subsequent metamorphism they have undergone, it is difficult to say; but there is certainly a much closer family resemblance, so to speak, among the metamorphic strata, than there is among the strata of any subsequent system.

Theories of Metamorphism.

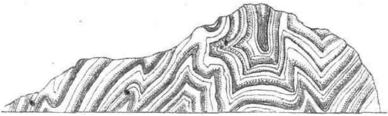
151. Although mineral metamorphism, as stated in the context, has taken place locally and partially among rocks of all ages, it is yet pre-eminently characteristic of the strata under review; hence the numerous hypotheses that have been advanced to account for the change. As in nature we have generally a combination of causes, so have most of those hypotheses, by adhering to some special agency, failed to account for the phenomena in question. The problem of Metamorphism is altogether a very difficult one, and one involving so many questions in the obscurer departments of chemistry, electricity, and crystallography, that geology must rest satisfied in the mean time with indicating rather than defining the nature of the operative causes. The most obvious and general of these may be briefly enumerated:—1. *Heat by contact*, as when any igneous mass, like lava, indurates, crystallises, or otherwise changes the strata over or through which it passes; 2. *Heat by transmission, conduction, or absorption*, which may also produce metamorphism, according to the temperature of

the heated mass, the continuance of the heat, and the conducting powers of the strata affected; 3. *Heat by permeation of hot water, steam, and other vapours*, all of which, at great depths, may produce vast changes among the strata, when we recollect that steam, under sufficient pressure, may acquire the temperature of molten lava; 4. *Electric and galvanic currents* in the stratified crust, which may, as the experiments of Mr Fox and Mr Hunt suggest (passing galvanic currents through masses of moistened pottery clay), produce cleavage and semi-crystalline arrangement of particles; 5. *Chemical action and reaction*, which, both in the dry and moist way, are incessantly producing atomic change, and all the more readily when aided by an increasing temperature among the deeper-seated strata; 6. *Molecular arrangement by pressure and motion*—a silent but efficient agent of change, as yet little understood, but capable of producing curious alterations in internal structure, especially when accompanied by heat, as we daily see in the manufacture of the metals, glass, and earthenware.

[The recent experiments of Deville, by which he obtains artificially crystallised minerals of great regularity and beauty by heating the amorphous substances in a slow current of some gas, such as hydrochloric acid, are likely also to throw further light on the nature and process of mineral metamorphism. Hydrochloric acid, for instance, is not an unfrequent product in volcanic districts, and we can readily perceive how its escape in a heated state through chinks and fissures might assist in coating these (as they often are) with various mineral crystals. What can be accomplished superficially in this way, may likewise take place in semi-fused masses by permeation through their minute interstitial cavities.]

152. Such are the more general and likely causes of rock-metamorphism, and as it is possible that several of them may be operating at the same time, the student will perceive that no hypothesis that limits itself to any one agent can be accepted as sufficient and satisfactory. Heat and chemical action and pressure are, no doubt, the chief causes of change, and by them we can readily account for new crystalline arrangements in semi-fused masses, for fissures, joints, and cleavage, and in a great measure for that flexuring and folding of the stratified laminæ known as foliation. And if to these we add electricity, and new crystallographic and molecular arrangement under further chemical reaction, we call in a sufficiency of agency, though we may not always perceive the precise modes of action. We can readily see how a mass of sand may be consolidated into sandstone by pressure, or firmly agglutinated by the percolation of some cementing material; but we cannot account for the conversion

of such a sandstone into a sparkling crystalline rock studded with independent crystals of garnet and chiastolite, and having



Flexured and Contorted Gneissose Rocks in Glen Quoich.—Murchison.

all its layers flexured, folded, and contorted, without calling in the agencies of heat, pressure, and new molecular arrangement.

153. It is by such agencies that geologists have in like manner endeavoured to account for the phenomena of *cleavage* and *foliation*—their theories being regarded as *mechanical* or *chemical*, according as they are founded on physical or on chemical considerations. Thus, those who regard cleavage as a minute species of jointing, generally running parallel to great axes of elevation, and altogether independent of the strike or dip of the strata through which it passes, adopt the mechanical theory of great lines of cosmical uprise and contraction, which produced immense pressure on the irregular particles or interstitial cavities of the cleaved masses; while those who regard it as a species of crystallisation or new molecular arrangement adopt a chemical view, and ascribe the appearances to the long-continued, but as yet imperfectly understood, operation of electrical or chemical forces. Professor Sedgwick, for instance, who has long directed his attention to metamorphic phenomena, propounds a chemico-electrical hypothesis, by which "crystalline or polar forces have re-arranged whole mountain-masses, producing a beautiful crystalline cleavage, passing alike through all the strata;" while Professor Phillips appeals in the main to "mechanical forces compressing the sediment at right angles to the lines of cleavage." On the other hand, Mr Daniel Sharpe attempts to combine with this mechanical theory "the action of some peculiar crystalline force;" while Messrs Sorby and Tyndall adopt the purely mechanical view—the former maintaining that the flattish unequiaxed particles of the ancient mud and sand greatly aided the compressing force in producing cleavage; and the latter that the result was unaided by the shape of the particles, but was caused by the extension under pressure of the minute interstices which must exist in even the most finely levigated mudstones. As with

cleavage so with foliation; one set of theorists advocating new molecular arrangements of the mass, and another endeavouring to account for the flexures and crumplings by mechanical pressure on the semi-fused laminæ of the respective strata. Whatever the cause producing the *foliated texture*, it is evidently closely allied, if not identical, with that producing the *structural contortions* and *foldings* of the strata themselves, as evidenced in the instructive section given in the preceding paragraph. In a limited elementary outline, it would be out of place to do more than indicate the bearings of the question; and we need only remark that much wider observation and a more intimate acquaintance with the facts of terrestrial chemistry and magnetism are necessary before geology can hope to arrive at satisfactory theories respecting such intricate phenomena.

154. To those who may feel inclined to pursue the study of metamorphism, cleavage, and foliation—and a nobler field for the geological chemist and physicist does not exist within the range of the science—we would recommend the *Theoretical Researches* of Sir H. de la Beche, Bischoff's *Physical Researches*, Hopkin's *Terrestrial Magnetism*, Mr Hunt's researches in the *Memoirs of the Geological Survey*, and the papers of Professors Sedgwick and Phillips, Messrs Sharpe, Sorby, D. Forbes, and Tyndall, in the *Transactions and Journal of the Geological Society*, vols. iii. and v.; the *Report of the British Association* for 1843; *Edin. Phil. Journal*, vols lv.; and the fourth series of the *Philosophical Magazine*, vols. xi. and xii.

IX.

PALÆONTOLOGY.—GENERAL CHARACTERISTICS OF FOSSILS.

155. BEFORE entering on the fossiliferous systems, it may be well to remind the student that the department of his subject having special reference to fossils is termed *Palæontology* (*palaios*, ancient, *onta*, beings, and *logos*, a discourse), or that which treats of the former life of the globe; while the department more immediately concerned with the mere rocks or strata is spoken of as *Lithology* (*lithos*, a stone), or Physical Geology. The palæontological and lithological aspects of a system are therefore two very different things, and convey much the same meaning as when we speak of the *stratigraphical* order of its rocks, and the *zoological* or *botanical* characters of its fossils. To describe fully any system or suite of strata, two things are necessary—*first*, to ascertain their mineral composition and physical relations, so as to determine the conditions under which they were deposited and the changes they may have subsequently undergone; and, *secondly*, to examine the character of their fossils, so as to arrive at some knowledge respecting the biological conditions of the region at the time of their formation. The student has been already furnished with aids to enable him to comprehend the lithology of a system; we shall now endeavour, as far as the scope of an elementary text-book will permit, to explain the general characteristics of fossils, what they are, the states in which they occur, and the terms and arrangements adopted by palæontologists in their comparisons of extinct with existing species.

Processes and Conditions of Petrifaction.

156. The term *fossil* is applied indiscriminately to all remains of plants or animals found imbedded in the solid strata, and con-

verted into stony or mineral matter. When petrifaction has not taken place, and the organism is merely imbedded in superficial clays and gravels, the term *sub-fossil* is that more properly applied. Thus, the bones and shells of the chalk, converted into limestone, and even harder than the rock itself, are "fossils" proper; while the shells of our raised beaches, and the gigantic bird-bones found in the river-silt of New Zealand, are merely "sub-fossil," or in the first stages of petrifaction. Fossils, whether vegetable or animal, are generally converted into the same substance as the rock in which they are imbedded; that is, if occurring in limestone they will be more or less calcareous; if in coal, bituminous; and if in sandstone, more or less arenaceous. It must not, however, be imagined that, because a fossil is found in limestone, it will be wholly calcareous; or in sandstone, that it will be arenaceous. The fact is, that fossils often present very anomalous and puzzling characters—being converted into flint, like many of those found in chalk, into ironstone, like some found in coal, or into iron-pyrites, like many found in clays and shales. In numerous instances the form and bulk of the organism is apparent and perfect; in others it is a mere impression of the external surface; while frequently the substance is altogether gone, and only a hollow cast of its shape is left in the rock in which it was originally imbedded. These and other states are common in every formation, and by a little practice the eye of the student will readily detect the slightest trace of organised structure in any mass of mineral matter. There is something so peculiar in the arrangement of organic parts—be it the structure of bone or shell, the cellular or ligneous texture of plants, or even the mere ornamentation of external surface—that at once arrests the eye, and enables it to distinguish between the organic fossil and the inorganic mineral that contains it. And where the naked eye may fail, a common pocket-magnifier will often enable the observer to detect the presence of an organism. In more obscure cases, and where the ordinary lens is too feeble to reveal the specific character of the fossil (such as in a mass of coal, for example), the most intricate structure of the organism can often be beautifully displayed by polishing thin slices of the substance, and submitting them to the higher powers of the microscope.

157. In whatever condition fossils may be found—whether converted into metallic pyrites, into a bituminous mass like coal, or into stone like flint or limestone—they may all, without much scientific error, be said to be *petrified*. The process of petrifac-

tion, generally speaking, consists in the infiltration of stony matter into the pores of vegetable or animal substances. In some instances the organic body has almost entirely disappeared, and the stony matter has been so gradually substituted, particle for particle, that the petrifaction presents a perfect resemblance in its minutest parts to the original structure. Petrifaction has been artificially imitated by burying bones in mud, clay, and lime, and it has been found that after a time the bones became black, harder, and heavier; and had the process been continued, they would have eventually been undistinguishable from true fossils. Springs holding lime or flint in solution are familiar examples of petrifying agents when they convert pieces of moss, straw, twigs, and branches into calcareous and siliceous matter. Lime and flint are perhaps the most abundant petrifying substances in nature; but many fossil bones and shells are converted into metallic crystals, vegetable remains into bituminous masses like coal, and not unfrequently trunks of trees have their forms perfectly preserved in strata of fine-grained sandstone. Without entering upon the obscure, and as yet little studied, processes by which organic substances are preserved in the crust of the earth, we may notice a few of the more obvious, rather with a view to indicate the nature of the subject than attempt to teach its details. A shell, like the common cockle, may be buried in a mass of calcareous mud, and when so enclosed it is of itself composed of carbonate of lime and a little animal matter. As it remains imbedded chemical changes take place—the animal matter decomposes and passes off in a gaseous state, and its place is supplied by an additional infiltration of lime from the mass. If iron in solution be present in the mud, the sulphuretted hydrogen arising from the animal decomposition will unite with the iron, and the shell will become coated or incrusted with shining iron pyrites, or sulphuret of iron. As the calcareous mass becomes consolidated into limestone-rock, the shell will also become hard and stony, but still preserving its form to the minutest ridge and corrugation of its exterior surface. By-and-by, carbonated waters may filtrate through the pores of the limestone; the shell may be dissolved entirely, and leave only a hollow cast of its form. Another change may now take place: water holding siliceous matter may percolate through the rock, and the hollow shell-cast be filled entirely with flint. As with flint, so with crystallised carbonate of lime, with iron pyrites, or even with a soft clayey deposit that yields to the scratch of the nail. All these are possible changes, and changes which every day present themselves

to the palæontologist; and as with a shell, so with a tooth, a fragment of bone, a fish scale, a mass of coral, the network of a leaf, or the woody fibre of a drifted pine-branch. The structure of the organism is always more or less preserved, and forms a basis for the petrifying solution, which thoroughly pervades and replaces it, particle for particle, without disturbing the arrangement of those parts on which its characteristic form depends. It is this form or external character which enables the palæontologist to compare and classify fossils with existing plants and animals; and it is this internal arrangement of cell and fibre, as revealed to the microscope, that enables him to detect bone from shell, the bone of a bird from the bone of a mammal, or the tissue of an endogenous from that of an exogenous or true timber tree.

158. Having ascertained whether his fossil belongs to the vegetable or animal kingdom, the next endeavour of the palæontologist is to discover to what class or family in existing nature it offers most points of affinity or resemblance. Considering the obscure and fragmentary condition in which fossils are frequently found, and bearing also in mind that most of the species and genera with which the palæontologist has to deal are long since extinct, it is a matter of congratulation that so much has been done to throw light on the botany and zoology of the past, rather than a subject of reproach that we can do little more than merely attach provisional names to hundreds of organisms that are daily being discovered. If, in the living world, we have the dictum of a Cuvier—"that the difference between two *species* is sometimes entirely inappreciable from the skeleton, and that even *genera* cannot always be distinguished by osteological characters"—what marvel need there be at the doubts that surround so many of the discoveries of the palæontologist? And where a Cuvier and an Owen, an Agassiz and a Milne Edwards, a Forbes and a De Koninck, have hesitated to pronounce, the student of geology need not be ashamed to own that he only knows that this is a marine shell, and that a coral; this the scale of a fish, that the bone of a reptile; this the tooth of a shark, that the grinder of a mammal; this the frond of a fern, and that the reticulated leaf of a true timber-yielding tree. It is owing to the uncertainty that attaches to many fossil remains, and to the fact that so many belong to races now extinct, that the science is cumbered with synonymes and species — a difficulty that is yearly disappearing, and one that need neither deter nor discourage the earnest inquirer.

General Characteristics of Plants and Animals.

159. Before the palæontologist can hope to determine the nature of fossil plants and animals—before he can classify them and compare them with those now existing, or determine all the conditions under which they must have flourished—he must acquaint himself with the leading facts of Botany and Zoology. In an elementary work of this kind, it would be out of place to enter at length into the details of these sciences; but as a certain amount of knowledge is necessary to the understanding of subsequent descriptions, we may shortly recapitulate the classification of plants and animals as generally adopted by botanists and zoologists, noting such additions as palæontologists have found it necessary to insert, with a view to embrace extinct families or genera. The assistance which geology has conferred, and the new light its deductions have thrown on the other branches of Natural Science, are not among the least of its claims to general attention. The reconstructing, as it were, of so many extinct forms of existence has given a new significance to the science of LIFE; and henceforth no view of the vegetable or animal kingdoms can lay claim to a truly scientific character that does not embody the discoveries of the palæontologist. In fact, so inseparably woven into ONE GREAT SYSTEM are fossil forms with those now existing, that we cannot treat of the one without considering the other; and can never hope to arrive at a knowledge of Creative Law by any method which, however minute as regards the one, is not equally careful and accurate as regards the other. "It has been found," says Professor Lindley in speaking of the fossil *flora*, and the remark is equally applicable as regards the *fauna*, "that neither a barren nomenclature, destitute of all attempt at determining the relations that former species bore to those of our own era, nor supposed identifications of species by vague analogies by partial views of structure, are sufficient to satisfy the geological inquirer; on the contrary, it is now distinctly seen that nothing short of a most rigorous examination is likely to serve the ends of science, and that all conclusions that are not drawn from the most precise evidence that the nature of the subject will afford, must either be rejected, or at least received with the greatest caution."

160. Vegetables have been arranged into two grand divisions —CELLULAR and VASCULAR:—

I. CELLULAR—Without regular vessels, but composed of fibres which sometimes cross and interlace each other. The *Confervæ* (green

scum-like aquatic growth), the *Lichens* (which incrust stones and decaying trees), the *Fungi* (or mushroom tribe), and the *Algæ* (or sea-weeds), belong to this division. In some of these families there are no apparent seed-organs. From their mode of growth—viz., sprout-like increase of the same organ—they are known as *Thallogens* or *Amphigens*.

II. VASCULAR—With vessels which form organs of nutrition and reproduction. According to the arrangement of these organs, vascular plants have been grouped into two great divisions—*Cryptogamic* (no visible seed-organs), and *Phanerogamic* (apparent flowers or seed-organs). These have been further subdivided into the following classes:—

1. *Cryptogams*—Without perfect flowers, and with no visible seed-organs. To this class belong the *mosses, equisetums, ferns*, and *lycopodiums*. It embraces many fossil forms allied to these families. From their mode of growth—viz., increase at the top or growing point only—they are known as *Acrogens*.
2. *Phanerogamic monocotyledons*—Flowering plants with one cotyledon or seed-lobe. This class comprises the *water-lilies, lilies, aloes, rushes, grasses, canes*, and *palms*. In allusion to their growth—by increase within—they are termed *Endogens*.
3. *Phanerogamic gymnosperms*—This class, as the name indicates, is furnished with flowers, but has naked seeds. It embraces the *cycadeæ* or pine-apple tribe, and the *coniferæ* or firs. In allusion to their naked seeds, these plants are also known as *Gymnogens*.
4. *Phanerogamic dicotyledons*—Flowering plants with two cotyledons or seed-lobes. This class embraces all forest trees and shrubs—the *compositæ, leguminosæ, umbelliferæ, cruciferæ*, and other similar orders. None of the other families of plants have the true woody structure, except the *coniferæ* or firs, which seem to hold an intermediate place between monocotyledons and dicotyledons; but the wood of these is readily distinguished from true dicotyledonous wood. From their mode of growth—increase by external rings or layers—they are termed *Exogens*.

Such are the fundamental groupings of existing plants, and under one or other of these divisions palæophytologists have attempted to arrange their fossil flora. It must be confessed, however, that fossil botany is by no means in a very satisfactory state; and as we have forms to which there are no existing generic analogues (*lepidodendron, sigillaria, stigmaria*, &c.), so it may turn out that there have been in former epochs whole classes of vegetation, forming, as it were, intermediate links between the thallogens, acrogens, gymnogens, and endogens of the botanist, and yet belonging to neither. In naming fossil plants whose affinities are unknown, the palæontologist in general adopts some term which will best convey an idea of their appearance, as *lepidodendron* or scaly-bark tree, *stigmaria* or dotted-bark, and the like. Where some resemblance or apparent affinity exists, the name of the living plant is adopted, with the termination *ites* or *lites* (*lithos*,

a stone) to show that the organism is fossil. Thus we have *chondrites* (resembling the living sea-weed *chondrus*); *calamites* (resembling the *calamus* or reed); and *cycadites* (like, or allied to, the existing *cycas revoluta*). In every instance, the binomial or two-name system of nomenclature is closely adhered to—the former term indicating the *genus*, the latter the *species*, to which the fossil belongs, — as *Sigillaria obovata*, the sigillaria having oval-shaped leaf-scars; *Sigillaria reniformis*, that marked by kidney-shaped leaf-scars.

[Founding, *first*, on the different modes of reproduction; *second*, on the aspect of the reproducing organs; *thirdly*, on the primary development; and, *fourthly*, on the ultimate development of the plant, botanists arrive at a scheme of classification which may be tabulated as follows:—

SPERMOCARPS or PHANEROGAMS	ANGIOSPERMS	EXOGENS	Dicotyledons	Herbs, Shrubs, Timber trees.
		ENDOGENS	Monocotyledons	Grasses, Sedges, Palms
	GYMNOSPERMS	GYMNOGENS	Polycotyledons	Cycads and Conifers.
SPOROCARPS or CRYPTOGAMS	ANGIOSPORES	ACROGENS	Sporogams	Clubmosses, Lycopods
			Thallogams	Ferns and Horsetails.
			Axogams	Mosses and Liverworts.
	GYMNOSPORES	AMPHIGENS	Hydrophytes	Algæ and Confervæ.
			Aerophytes	Lichens.
			Hysterophytes	Fungi or Mushrooms.

Subdividing still further according to their most marked characteristics, whether external or internal, the botanist arranges all the forms of Vegetable Life into some 60 or 70 orders, about 300 genera, and nearly 100,000 species. As most of these distinctions, however, are founded on the form and connection of the flower, fruit, and leaf—organs which rarely occur in connection in a fossil state—the palæontologist is guided in the main by the great structural distinctions already adverted to, and not unfrequently by the simple but unsatisfactory test of "general resemblance."]

161. Animals, according to Cuvier—and it is the Cuvierian classification which in a great measure still regulates our notions of the animal kingdom—may be arranged into four great divisions or sub-kingdoms,—the VERTEBRATA, MOLLUSCA, ARTICULATA, and RADIATA:—

I. VERTEBRATA—Animals which have a skull containing the brain, and a spine or back-bone (vertebræ) enclosing the principal trunk of the nervous system, commonly called the spinal marrow. They have red blood; and are further subdivisible into *mammalia* (sucklers), *aves* (birds), *reptilia* (reptiles), *amphibia* (amphibious), and *pisces* (fishes). These orders are susceptible of still more minute division into sub-orders, families, genera, and species, according to structure, form, mode of life, and other peculiarities. Thus mammals, according as they bring forth their young, are either *placental* like the ox, or *marsupial* like the kangaroo; birds are *raptorial* (seizers of their prey), *grallatorial* (waders), and so forth, according to habit; reptiles are *batrachian* (frog-like), *ophidian* (serpent-like), &c.; and fishes are *osseous* or *cartilaginous*, according as they are furnished with a skeleton of bone or of cartilage.

II. MOLLUSCA—Animals of this division have no internal skeleton (*mollis*, soft); the muscles are attached to the skin, which in many species is covered with a shell. The nervous system and viscera are composed of detached masses united by nervous filaments. They have a complete system of circulation and particular organs for breathing by. Animals with bivalve, univalve, and chambered shells belong to this division, though many molluscs, as the common slug, have no shell. According as they possess a distinct head, they have been arranged into *cephala*, *paracephala*, *acephala*, *tunicata* (shell-less), and *polyzoa*, or living in compound groups. These orders are further subdivided according to the organs of motion, the breathing apparatus, or other peculiarities; hence we have *cephalapods* (head-footed), *gasteropods* (belly-footed), *brachiopods* (arm-footed), and so forth.

III. ARTICULATA—Animals of this sub-kingdom have, as the name implies, articulated or jointed bodies, like the worms, crabs, and insects. Their nervous system consists of two long cords, ranging along the body, and swelling out in different parts into knots or ganglia. The orders embraced by the division are *arachnida* (spiders), *insecta* (insects), *myriapoda* (hundred-feet), *crustacea* (crabs), *annelida* (worms), and *entozoa* (internal parasites). These orders are each susceptible of many subdivisions—taking form, mode of life, and other peculiarities as the grounds of distinction. Thus the crustacea are *decapods* (ten-footed), *phyllopods* (leaf-footed), &c., according to their organs of motion; or *macrurus* (long-tailed), *brachyurus* (short-tailed), *xiphosurus* (sword-tailed), taking their caudal terminations as grounds of distinction.

IV. RADIATA—Comprises all those animals whose bodies have a radiated or star-like arrangement of parts. In animals of this division, the organs of sense and motion are circularly disposed round a centre or axis; there is no distinctly marked nervous system, and the circulation in many species can hardly be discerned. Many of the radiata are fixed, as the corals; others move and float about, as the star-fish and sea-urchin. They may be arranged into the *echinodermata* (sea-urchins and star-fishes), the *acalephæ* (sea-nettles or jelly-fish), *polypi* (coral-animals and sea-anemones), and *protozoa* (sponges and other obscure and lowly forms). These, as in the other sub-kingdoms, are subdivisible into numerous families—each having some peculiarity of structure, growth, or habit.

[The subjoined TABULATION may render more apparent the subdivisions and relations of the animal kingdom, and enable the student to comprehend more readily the position of the extinct forms (of which we have to treat) in the scale of animated existence:—

VERTEBRATA,

Or animals with back-bone and bony skeleton, and comprehending MAMMALIA, AVES, REPTILIA, and PISCES.

I. MAMMALIA, or *Sucklers*, subdivided into Placental and Aplacental.

1. PLACENTAL, bringing forth mature young.

BIMANA (*Two-handed*)—Man.
QUADRUMANA (*Four-handed*)—Monkeys, Apes, Lemurs.
CHEIROPTERA (*Hand-winged*)—Bats, Vampyre-bats, Fox-bats.
INSECTIVORA (*Insect-eaters*)—Mole, Shrew, Hedgehog, Banxring.
CARNIVORA (*Flesh-eaters*)—Dog, Wolf, Tiger, Lion, Badger, Bear.

PINNIPEDIA (*Fin-footed*)—Seals, Walrus.
RODENTIA (*Gnawers*)—Hare, Beaver, Rat, Squirrel, Porcupine.
EDENTATA (*Toothless*)—Ant-eater, Armadillo, Pangolin, Sloth.
RUMINANTIA (*Cud-chewers*)—Camel, Llama, Deer, Goat, Sheep, Ox.
SOLIDUNGULA (*Solid-hoofs*)—Horse, Ass, Zebra, Quagga.
PACHYDERMATA (*Thick-skins*)—Elephant, Hippopotamus, Rhinoceros, Pig.
CETACEA (*Whales*)—Whale, Porpoise, Dolphin, Lamantin.

2. APLACENTAL, bringing forth immature young.

MARSUPIALIA (*Pouched*)—Kangaroo, Opossum, Pouched Wolf, &c.
MONOTREMATA (*One-vented*)—Ornithorhynchus, Porcupine-ant-eaters.

II. AVES, or BIRDS.

RAPTORES (*Seizers*)—Eagles, Falcons, Hawks, Owls, Vultures.
INSESSORES (*Perchers*)—Jays, Crows, Finches, Sparrows, Thrushes, &c.
SCANSORES (*Climbers*)—Woodpeckers, Parrots, Cockatoos, &c.
COLUMBÆ (*Pigeons*)—Common Dove, Turtle Dove, Ground Dove.
RASORES (*Scrapers*)—Barnfowl, Partridge, Grouse, Pheasant.
CURSORES (*Runners*)—Ostrich, Emeu, Apteryx.
GRALLATORES (*Waders*)—Rails, Storks, Cranes, Herons.
NATATORES (*Swimmers*)—Divers, Gulls, Ducks, &c.

III. REPTILIA, subdivided into Reptiles Proper and Batrachians.

1. REPTILES PROPER.

CHELONIA (*Tortoises*)—Turtles, Tortoises.
LORICATA (*Covered with Scutes*)—Crocodile, Gavial, Alligator.
SAURIA (*Lizards*)—Lizard, Iguana, Chameleon.
OPHIDIA (*Serpents*)—Vipers, Snakes, Boas, &c.

2. BATRACHIANS, or FROGS.

ANOURA (*Tail-less*)—Tod, Frog, Tree-frog.
URODELA (*Tailed*)—Siren, Triton, Salamander.
APODA (*Footless*)—Lepidosiren, Blindworm.

IV. PISCES, or FISHES.

SELACHIA (*Cartilaginous*)—Chimæra, Sharks, Sawfish, Rays.
GANOIDEA (*Enamel-scales*)—Amia, Bony-pike, Sturgeon.
TELEOSTIA (*Perfect-bones*)—Eels, Salmon, Herring, Cod, Pike, &c.
CYCLOSTOMATA (*Circle-mouths*)—Lamprey.
LEPTOCARDIA (*Slender-hearts*)—Amphioxus.

INVERTEBRATA,

Or animals void of back-bone and bony skeleton, and comprehending ARTICULATA, MOLLUSCA, RADIATA, and PROTOZOA.

I. ARTICULATA, subdivided into Articulates and Vermes.

1. ARTICULATA, or Jointed Animals Proper.

INSECTA (*Insects*)—Beetles, Butterflies, Flies, Bees.
MYRIAPODA (*Many-feet*)—Scolopendra, Centipedes.
ARACHNIDA (*Spiders*)—Spiders, Scorpions, Mites.
CRUSTACEA (*Crust-clad*)—Crayfish, Crabs, Shrimps, Woodlice.
CIRRHOPODA (*Curl-feet*)—Acorn-shells, Barnacles.

2. VERMES, or Worms Proper.

ANNELIDA (*Small-rings*)—Lobworm, and almost all the marine worms.
ROTIFERA (*Wheel-bearers*)—Rotifers, Hydatina.
GEPHYRIA (*Intermediates—urchin-like*)—Sipunculus, Echinurus.
LUMBRICINA (*Earth-worms*)—Earth-worms, Nais.
HIRUDINEI (*Leeches*)—Leeches, Branchellion.
TURBELLARIA (*Turbellaries*)—Planaria, Ribbon-worms.
HELMINTHES (*Gut-worms*)—Intestinal worms.

II. MOLLUSCA, subdivided into Mollusca and Molluscoida.

1. MOLLUSCA, or Shell-fish Proper.

CEPHALOPODA (*Head-footed*)—Cuttle-fish, Octopus, Calamary, Nautilus.
PTEROPODA (*Wing-footed*)—Clio, Hyalæa.
GASTEROPODA (*Belly-footed*)—Snails, Slugs, Whelks, Cowries.
ACEPHALA (*Headless*)—Oysters, Mussels, Cockles, Shipworms.
BRACHIOPODA (*Arm-footed*)—Terebratula, Lingula.

2. MOLLUSCOIDA, or Mollusc-like Animals.

TUNICATA (*Coated, but Shell-less*)— Biphora, Simple and Compound Ascidians.
POLYZOA (*Compound animals*) or BRYOZOA (*Moss-like animals*) — Flustra, Eschara, Plumatella, &c.

III. RADIATA, or ZOOPHYTES—Ray-like Animals.

ECHINODERMATA (*Urchin-skinned*)—Sea-urchins, Star-fishes.
ACALEPHÆ (*Sea-nettles*)—Jelly-fish, Beroes.
POLYPI (*Many-feet*)—Coral-animals, Sea-anemones, Hydras.

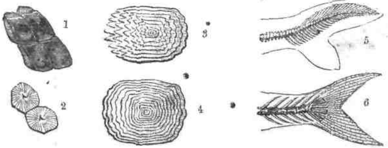
IV. PROTOZOA, or LOWEST-LIFE—Globular Animals.

INFUSORIA (*Infusories*)—Monads, Volvoces, Vorticella.
PORIFERA (*Pore-bearers*)—Sponges, Fresh-water Sponges.
RHIZOPODA (*Root-footed*)—Amœba, Polythalamia (Foraminiferæ).]

162. Like all other systems of classification, the preceding is in a great measure artificial and provisional, and must, before it presents an adequate view of animated nature, receive many modifications and corrections. As it is, existing aminals can be arranged more or less harmoniously under its subdivisions; and even the majority of extinct forms take rank and order without much incongruity. The new and marvellous forms which Palæontology has added, and is daily adding, to the fauna of the world, are merely filling up the details, the variety and richness of the patterns on the web of created existence, and instead of perplexing, serve as intermediate and connecting links between points which the zoologist had hitherto considered abnormal and aberrant. The encrinites and trilobites, the sauroid and theroid animals of the palæontologist, are throwing new light and consistency on the plan of creation; and henceforth there can be

no adequate scheme of classification which does not embrace in its categories extinct as well as recent forms. In treating of fossil forms, the palæontologist, though he has had to establish a vast number of new and provisional species, has had to invent no new scheme of classification or zoölogical nomenclature, and with few exceptions the vocabulary of Zoology is the same as that of Palæontology. The termination *oid* (*eidos*, form or likeness) is of frequent occurrence, and merely expresses resemblance, as *sauroid* (lizard-like), *mytiloid* (mussel-like,) &c.; while the termination *ite* or *lite* (*lithos*, a stone) indicates the fossil nature of the organism, as *ichthyolite* (fish-fossil), *ichnite* (fossil footprint), and the like. Perhaps one of the widest deviations from zoological nomenclature is that adopted by Agassiz in treating of fossil fishes, and as this is met with at every turn in speaking of these interesting remains, the following explanations may be of use to the student.

163. As the scales or external coverings (the *exo-skeletons*) are often the best preserved portions of the palæozoic fishes, which are chiefly cartilaginous, and therefore deficient in a bony or endo-skeleton, it occurred to M. Agassiz to arrange fishes into four great orders according to the structure of the external parts



1, Ganoid; 2, Placoid; 3, Ctenoid; and, 4, Cycloid Scales.
5, Heterocercal; 6, Homocercal Tail.

—namely, the ganoid, placoid, ctenoid, and cycloid. 1. The *ganoid* (*ganos*, splendour) are so called from the shining or enamelled surface of their scales. These scales are generally angular, are *regularly* arranged, entirely cover the body, are composed internally of bone, and coated with enamel. Nearly all the species referable to this division are extinct; the sturgeon and bony-pike of the North American lakes are living examples. 2. The *placoid* (*plax*, a plate) have their skins covered irregularly with plates of enamel, often of considerable dimensions, but sometimes reduced to mere points, like the shagreen on the

skin of the shark, or the prickly tubercles of the ray. This order comprises all the existing cartilaginous fishes, with the exception of the sturgeon. 3. The *ctenoid* (*kteis, ktenos*, a comb) have their scales of a horny or bony substance without enamel, and jagged on the posterior edge like the teeth of a comb. The perch may be taken as a living example of this division. 4. The *cycloid* (*cyclos*, a circle) have smooth, bony, or horny scales, also without enamel, but entire or rounded at their margins. The herring and salmon are living examples of this order, which embraces the majority of existing species. Besides these distinctions, it is also usual to recognise fossil fishes as heterocercal and homocercal; that is, according as their tails are unequally or equally lobed. Thus in *heterocercal* species (*heteros*, different, and *cercos*, a tail) the tail is chiefly on one side, like that of the shark and sturgeon, the back-bone being prolonged into the upper lobe; in *homocercal* species (*homos*, alike) the lobes of the tail are equal or similar, as in the salmon and herring. In palæontology this distinction, as will afterwards be seen, is an important one, all the fishes of the palæozoic periods being heterocercs, the equally-lobed and single-rounded tails being characteristic of more recent and existing species.

164. Besides those distinctions which depend on the structure and form of plants and animals, there are others which should be constantly kept in view by the geologist; namely, those depending on climate, habitat, and mode of life. The plants of the tropics are very unlike those of polar regions, both in number, size, and character; the trees of a genial climate are always more uniform and equable in growth than those of a region subjected to extremes of heat and cold; marine plants and animals are essentially different from those inhabiting fresh waters; aquatic plants and amphibious animals present a very different appearance from those constantly existing upon dry land; while the life of the plain and the marsh is altogether distinct from that which flourishes in the dry and lofty upland. Each race of plants and animals is, moreover, perfectly adapted for the functions it has to perform in the economy of nature; and is furnished with peculiar organs, according to the kind of food upon which it lives, and the other habits it displays. Thus, one set of organs indicates swiftness, another strength, a third prehensile or seizing powers, a fourth climbing, leaping, or swimming powers, a fifth that the animal lives on roots, on herbage, or on the flesh of others. As in the vegetable and animal economies of the present day, so in all former epochs;

and thus the geologist, by analogy and comparison, is able to decide as to the character of the fossil plants and animals which he discovers. He finds in their characters and skeletons a key to the modes of their existence, and can tell with precision whether they lived in the waters or on dry land, in fresh or in salt water, in a cold or in a hot climate; whether animals browsed upon plants or lived upon other animals; whether they are furnished with organs indicating an amphibious existence; and in general can determine their character and modes of existence. Moreover, as certain classes of plants and animals indicate certain conditions of the world, the geologist will be enabled by their remains to decipher the past history of our globe, and so arrive at that which is the aim and object of all true geological research.

NOTE, RECAPITULATORY AND EXPLANATORY.

165. In the preceding chapter we have endeavoured to point out the more prominent characteristics of fossils, that the student may be prepared to enter with intelligence on the consideration of the Fossiliferous Systems. These systems, it has been stated, may be viewed in two great aspects, either as regards their mere mineral and physical relations, or as regards the plants and animals found fossil in their strata. The former constitutes the Lithology of a formation, the latter its Palæontology, and both must be taken into account in attempting to arrive at a knowledge of the cosmical conditions under which its strata were deposited. Some acquaintance with botany and zoology is, therefore, indispensable to the geologist; not that he is to work out the details of these sciences as a professed botanist or zoologist, but that he must know enough of their general principles to be able to apply them to the solutions of his own special problems. For this purpose he should acquaint himself with the leading features of plants and animals; their classification and relations in the scale of being; their habits and mode of life; their geographical dispersion, as influenced by food and climate; and, above all, their mutual dependence and connection as exponents of terrestrial conditions. As a geologist, a little practice will soon enable him to distinguish between the concentric layers of exogenous and the pitted fibrous tissue of endogenous wood;

between the reticulated venation of a dicotyledonous and the parallel venation of a monocotyledonous leaf, and between the vascular structure of a terrestrial shrub and the cellular mass of a sea-weed. So also he will readily learn to distinguish the laminated texture of shell from the porous texture of bone; the bony texture of a fish-spine from the granular arrangement of a crustacean claw; the grinder of a mammal from the tooth of a shark; or the bone of a quadruped from the air-celled bone of a bird. To do this—leaving the more intricate anatomical distinctions to be worked out by the professed botanist and zoologist—is no very difficult task; the higher aim is to link in order the various grades of vegetable and animal life as developed in point of time and cosmical progress.

166. To the student who may wish to enter more fully into palæontological considerations, we may recommend perusal of Lindley and Hutton's *Fossil Flora;* Brongniart's *Vegetaux Fossiles;* the various vegetable *Monographs* of Goeppert; Dr Mantell's *Medals of Creation;* Dr Buckland's *Bridgewater Treatise;* Agassiz's *Poissons Fossiles;* Cuvier's *Ossemens Fossiles;* Owen's *Palæontology;* his *Fossil Mammals of Britain;* and his numerous papers and reports in the *Proceedings of the British Association, the Transactions and Journal of the Geological Society,* &c.; the *Decades* of the Geological Survey; Woodward's *Living and Fossil Shells;* Sowerby's *Mineral Conchology;* the general *Palæontographies* of Pictet, of D'Orbigny, and of Dunker and Von Meyer; the various *Monographs of the Palæontographical Society;* and as a hand-book of reference, Professor Morris's invaluable *Catalogue of British Fossils.*

X.

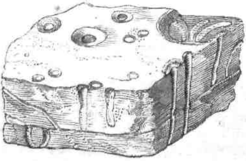
THE SILURIAN SYSTEM.

EMBRACING THE LOWER AND UPPER SILURIAN GROUPS—OR, 1, THE LLANDEILO; 2, THE WENLOCK; AND, 3, THE LUDLOW SERIES.

167. IMMEDIATELY above the Metamorphic rocks, which, as far as yet discovered, are entirely destitute of fossils, there occur certain slaty, gritty, and siliceous beds, in which traces of life are occasionally detected. These beds, often of vast thickness—as in North Wales, in Cumberland, and in the south of Scotland—are regarded by some geologists as a separate formation, distinct from the crystalline rocks below, and not to be confounded with true Silurian strata. It has, accordingly, been proposed to erect them into a distinct system, under the term *Cambrian*, because they are largely developed in North Wales (the ancient Cambria); or *Cumbrian*, because they are also well exhibited in the Lake district of Cumberland. In an elementary treatise like the present, it would be out of place to go largely into the grounds on which this opinion is founded; but we cannot avoid stating the fact for the guidance of beginners, that between the non-fossiliferous clay-slates on the one hand, and the highly fossiliferous Silurian flags on the other, there do occur in these islands a vast series of strata (generally known as "lower greywackè"), lithologically and apparently palæontologically distinct from the true Silurian system.

["In Bohemia, as in Great Britain and portions of North America, the lowest zone containing distinct fossil remains is underlaid by very thick basements of earlier sedimentary accumulations, whether sandstone, schist, or slate, which, though occasionally not more crystalline than the fossiliferous beds above them, have as yet afforded the rarest indications only of former beings in Britain, and none in other countries. In North America this formation may as yet be truly termed azoic; for along the western portion of Lake Superior, and in the country extending southwards into the State of Michigan, rocks of this class rise from beneath the Potsdam sandstone, or lowest formation in which Silurian fossils are known. Judging from the publications of the American authors Foster and Whitney on the azoic rocks of Lake Superior, of King on the State of Missouri, of Logan on the Bristol frontier, and of Engelmann on Texas, and placing them in relation to the works of James Hall and Dale Owen, it would appear that in those regions there exists a vast formation of strata, in parts metamorphic, of siliceous sandstones and chloritic and quartzose schists, characterised by the absence of organic remains, and the presence of a great abundance of iron ore. This is the *Huronian* or *Cambrian System* of Sir William Logan, chief geologist of Canada."—*Siluria*, 3d edition, p. 19.]

168. If it shall be found, in the progress of discovery, that the fossil forms in these strata are specifically the same as the fossils of the lower Silurian, then, whatever their mineral composition or stratigraphical relations, geologists will have no alternative but to regard them as a portion of the Silurian system. If, on the other hand, a majority of their fossil forms shall prove to be specifically different from those of the Silurian—even should there be a number of species common to both series of strata—then must we adhere to the views of Professor Sedgwick, and erect the *Cambrian* into a distinct and independent system. It is of little avail to point to mineral differences in some districts, and to unconformability in others, as evidences of a distinct lithological formation. The true exponents of a system, or world-period, are its fossil flora and fauna, and these in the Cambrian strata are so fragmentary and obscure that they admit of no positive deduction; some indistinct vegetable impressions (*fucites*), a few



Worm-burrows (scolithus linearis) in Sandstone.—Murchison.

worm-tracks and burrows (*scolithus* and *arenicolites*), a minute

branching zoophyte (*Oldhamia*, after Mr Oldham), and some small trilobitic crustaceans (*palæopyge*), being all, or nearly all, that have as yet rewarded the researches of the palæontologist. The tendency, however, of recent discovery is to carry the traces of life further and further back among these slaty and semi-crystalline strata; and the detection of new worm-tracks, graptolites, and trilobites in the schists of Skiddaw, Bohemia, and North America, is a fact too significant to be overlooked in geological speculation. The erection of the Cambrian strata into an independent Life-period may thus be regarded as an open question; and no detriment can arise to the progress of geology by regarding them in the mean time as the basis or "bottom-rocks" of the Silurian system.

169. These so-called Cambrian strata, and those now regarded as unmistakably Silurian, constitute what were formerly known as the *Greywackè* or *Transition* formation; the former term being a German word applied to certain pebbly or gritty slates of a grey rusty colour which occur in the series, and the latter having reference to their fossil character, and denoting the supposed transition of the world from non-fossiliferous to fossiliferous conditions of deposit. The term greywackè is now seldom employed, or employed only to designate a peculiar slaty siliceous grit, and the precision of fossil inquiry has all but exploded the idea of a transition period. The strata to which we now refer—that is, the vast suite that lies between the non-fossiliferous slaty-schists and the old red sandstone—being very fully developed in that district of country between England and Wales anciently inhabited by the Silures, the term *Silurian* has been applied to them, and the system very carefully worked out both in its mineral and fossil aspects. It is to this system of strata, so typically displayed in the counties of Montgomery, Radnor, and Salop—the Siluria of the ancient Britons—that the attention of the student is about to be directed. And here it may be remarked that the formation, originally so carefully and zealously investigated by Sir Roderick Murchison, from 1831 to 1839, has since found its full equivalents, both lithologically and palæontologically, in several regions, especially in the south of Scotland, in Bohemia, Scandinavia, Russia, and North America.

LOWER AND UPPER SILURIAN GROUPS.

170. In whatever condition the metamorphic rocks were at first laid down in the seas of deposit, we have seen that a common crystalline aspect now pervades the whole series, and that

the usual alternations of sedimentary matter are all but obliterated. We cannot say, for example, which stratum was originally of clay-silt, which of sand, or which of gravel. All these distinctions are effaced, and we cannot arrive at any satisfactory conclusion as to the waves and tides and currents by which they were aggregated, or the nature of the seas in which they were deposited. The case is widely different with the Silurian strata. Every alternation is distinct and evident: beds of slaty sandstone and pebbly conglomerate, shaly mudstone, clays, and limestones follow one another in frequent succession, and present so slight a change in their mineral structure, that we can readily judge of the conditions under which they were originally deposited. Some of the sandstones are finely laminated, and bear evidence of tranquil sediment; some are ripple-marked, and testify to the presence of tides or gentle currents; while others are pebbly conglomerates, and bespeak the existence of waves and gravel-beaches, such as we witness at the present day. Of the shales or argillaceous beds, some have evidently been thrown down in deep water as soft black mud, while others have been formed in shallower bays, and contain a certain admixture of sand, with sea-shells, such as are found at no great depth from the shore. Of the limestones or calcareous strata, many are replete with the remains of corals and shells, and recall the existence of seas in which the coral-polype reared its reefs, and shell-fish congregated in beds like the oyster and mussel of our own times. Indeed, the abundant presence of fossil zoophytes, corals, molluscs, and crustaceans, tells of varying conditions of water and sea-bottom, of light and heat, of tribes that secreted their nutriment from the ocean, or preyed on each other; and generally of a state of things different, it may be, but still analogous to that which we perceive in existing nature.

Lithological Composition.

171. The system which contains evidence of these varied conditions, consists essentially of argillaceous, arenaceous, and calcareous strata. Dark-coloured laminated shales, shales with concretions of limestone, beds of calcareous flagstone, thick-bedded sandstones and pebbly conglomerate, finely laminated micaceous sandstones, and shales and impure clayey limestones, and limestones of a concretionary structure, may be said to constitute the entire system. This description refers, of course, more especially to the strata as developed in England; and the student must be

prepared to meet with great lithological diversity in this as in every other system. Littoral deposits, and those in shallow seas, will differ from those in deep and still waters; while the thick muddy silt of a tidal estuary will be wholly unlike the calcareous accumulations of a coral-yielding sea. It is thus that the Silurians of England are more shaly and calcareous than those of the south of Scotland, and that the thin and scantily developed beds of Scandinavia can scarcely be compared with the gigantic and highly diversified formation of North America. Taking the typical district of Wales, which first threw light and consistency on the system, we find the strata clearly divisible into two great groups—a subdivision that holds good in almost every region where silurian rocks have been discovered. These "lower" and "upper" groups are further subdivisible into three well-defined series, as represented in the following synopsis:—

UPPER SILURIAN.

Ludlow Series.	Finely laminated reddish and greenish sandstones, locally known as "Tilestones." (In part, base of Devonian System.)
	Micaceous grey sandstone in beds of varying thickness.
	Argillaceous limestone (Aymestry limestone).
	Shale with concretions of limestone (Lower Ludlow).
Wenlock Series.	Concretionary limestone (Wenlock limestone).
	Argillaceous shale in thick beds (Wenlock shale).
	Shelly limestone and sandstone (Woolhope and Mayhill).
	Gritty sandstones and shales (Upper Llandovery).

LOWER SILURIAN.

Llandeilo Series.	Grits and sandy shales (Lower Llandovery).
	Thick-bedded whitish freestone (Caradoc sandstone).
	Dark calcareous flags and slates (Bala beds).
	Slaty flags and bands of limestone (Llandeilo and Lingula flags).
	Gritty flags and slates (Longmynd or "Bottom Rocks").

172. The preceding synopsis represents a thickness of about 8000 feet, and contains, of course, many alternations and gradations from freestone to sandy flags, from flagstones to shales, and from shales to calcareous flags and limestones of varying thickness and purity. In the south of Scotland the strata are more gritty and arenaceous, contain, as in Ireland, bands of impure anthracite or culm, and are not so clearly separable into series; in the north of Europe the system consists of calcareous shales, limestones, and flaggy mudstones, and is altogether scantily developed; in central Europe (Bohemia and Silesia) the succession is even more sharply defined than in Wales; while in North America a complex and repeated series of limestones, shales, sandstones, grits, and conglomerates seem to constitute the formation. It is difficult—perhaps impossible—to co-ordinate ex-

actly the strata of distant regions like England, Scandinavia, and North America ; still such co-ordinations have been attempted, and materially assist our conceptions of the system under review. Thus arranged, the Silurians of Scandinavia, which are only about 1000 feet in thickness, appear to find their equivalents in Britain as follows :—

Scandinavia.	*Britain.*
Calcareous flagstones,	Ludlow series.
Coralline limestone and shale,	Wenlock series.
Pentameral limestone,	Llandovery Rocks.
Black graptolite schist,	Moffat beds.
Orthoceratite limestone,	Llandeilo series.
Alum slates with olenus and agnostus,	Lingula beds.

According to Dr Bigsby, the Silurians of New York, and of North America generally, may be arranged into the following stages, sections, and groups—all less or more characterised by a prevalence of the generic forms which occur in the system as developed in Britain and the continent of Europe :—

Stages.	*Sections.*	*Group.*	*Prevailing Mineral.*
UPPER.	Upper Pentamerus Limestone, Delthyris—shaly Limestone, Lower Pentamerus Limestone, Waterlime Rocks,	H.	Limestone.
	Onodago Salt Rock,	G.	Sandy Shale.
	Coralline Limestone, Schoharie, Niagara Shale and Limestone,	F.	Limestone.
MIDDLE.	Clinton Rocks, Medina Sandstone,	E.	Sandstone.
	Oneida Conglomerate,	D.	Siliceous Conglomerate.
LOWER.	Hudson-River Rocks, Utica Slate,	C.	Clay.
	Trenton Limestone, Birdseye Limestone, Chazy Limestone,	B.	Limestone.
	Calciferous Sandstone, Potsdam Sandstone,	A.	Sandstone.

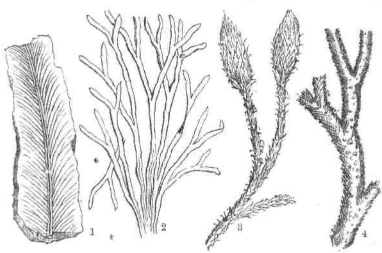
The same may be done with the strata of other districts ; and until the student attempts to co-ordinate in this manner, he can have no proper conception of the place which any particular set of strata hold in the system. The "Potsdam sandstones," "Trenton limestones," "Utica slates," and "Oneida conglomerates" of our American brethren have no significance till placed in juxtaposition with the Lingula flags and Llandeilo beds of our own Siluria. In fact, to determine the "equivalents" of strata in different and distant regions, and to place them, by a study of their fossils, on the same "horizon" in point of time, is the chief aim and object of legitimate geology.

Palæontological Characteristics.

173. The fossils of the Silurian system are eminently marine, and point to varying conditions of littoral and deep-sea deposits. They consist of numerous species and genera of zoophytes, echinoderms, mollusca, annelida, and crustacea. Traces of fishes have been found only on the uppermost verge of the system in England, or in beds, which by some are regarded as the proper basis of the old red sandstone; but in Russia, certain minute organisms occur abundantly in the lower strata, and are regarded by Dr Pander as the teeth (*conodonts*) of myxinoid fishes—an opinion, however, which is controverted by other palæontologists, who consider them more likely to be the hooklets or denticles of naked molluscs or annelids. As yet we have no indication whatever of a terrestrial fauna, and the accumulating evidence of recent research rather tends to dispel the hope of ever finding in true Silurian strata any of the higher manifestations of vertebrate existence. Still, we must not be too hasty in adopting conclusions of this kind, for it is not to be supposed that every portion of the system has been fully investigated. The strata as yet examined may have been deposited in deep water; and not till those deposited along the shores, and in the estuaries of the rivers which carried down the sand and mud of the period, have been equally well explored, can we pronounce with certainty either as to the kind or the amount of fossil remains. As it is, numerous genera of a varied and prolific sea-fauna have been detected, and these are invested with a high interest, as being the earliest evidences of life as yet known to geologists on our planet. And here let the student impress on his mind the fact, that, though the earliest known instances of vitality, there is in their structure no imperfection or trial-work. The corals of the Silurian seas, the shell-fish and crustacea of this primeval period, are as complex in their organisation, and as perfectly fitted for the functions they had to perform, as the corals and shell-fish and crustacea that now throng the existing waters. With regard to the vegetation of the period we have no very satisfactory evidence. *Fuci or sea-weeds* are not unfrequent in some localities; fragmentary stems, apparently of aquatic plants, are also by no means rare; and seed-spores and drift-twigs of plants apparently allied to the lycopodium or club-moss have been detected in the upper members of the system. Still, as a whole, the fossil flora of the Silurian epoch is by no means abundant or decisive, though the occasional bands of

anthracite and anthracitous shales would seem to indicate the development in certain areas of a *true terrestrial vegetation*.

174. Among the fossils specially characteristic of the period we may notice the following;—referring for fuller descriptions to the monographs mentioned in the Recapitulation, and for a complete list to Professor Morris's invaluable *Catalogue of British Fossils*, as well as to the list prepared by Messrs Morris and Salter for the last edition of Murchison's *Siluria*. The Silurian FLORA, as

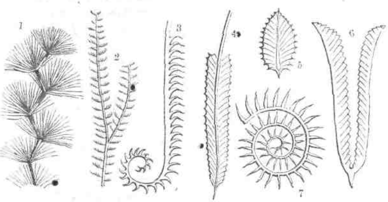


1, 2, Fucoids—Cruziana and Chondrites (?); 3, 4, Lycopodites—Lepidodendroid twigs, from the Upper Silurians of Lanarkshire.

already stated, *consists chiefly of algæ or marine plants*; and these generally in such an obscure condition as to prevent the botanist from determining their true affinities. They are known by such names as *chondrites*, from a resemblance to the *chondrus* of our own seas; *fucoides*, from their analogies to the *fucus; cruziana; palæochorda; lycopodites;* and the like—names which indicate resemblances rather than affinities, and this, in the present state of our knowledge, is all that palæontology can supply.

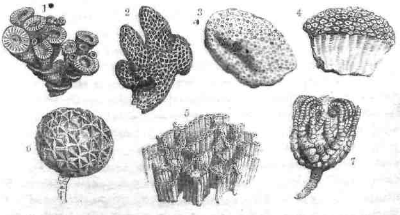
Of the FAUNA we know a great deal more, and can speak with some degree of certainty as to the conditions under which it lived and flourished. One of the most common forms is the *graptolite* (*grapho*, I write, and *lithos*, a stone), a peculiar family of zoophytes, so called from their resemblance to the sea-pens (*sertularia* and *virgularia*) of our own seas. These zoophytes, along with a few sponge-like forms (*acanthospongia, cliona*, &c.) and foraminiferæ, seem to have thronged the muddy bottom of the Silurian waters, are highly characteristic of the lower portion of

the system, and are known by such names as *graptolithus*, *rastrites* (*raster*, a rake), *diplograpsus* or double-graptolite, *didymograpsus*,



1, Oldhamia; 2, Protovirgularia; 3, Graptolites; 4, 5, Diplograpsus; 6, Didymograpsus; 7, Rastrites.

or twin-graptolite, and suchlike terms as best convey an idea of their external appearances. Among the corals and coralloid remains of the period there are also many peculiar genera, remarkable either for their sponge-like appearance, or for the cup-like shape of their structure. From the form or arrangement of their pores, these corals are known by such names as *cyathophyllum* or cup-coral; *arachnophyllum*, or spider-like coral; *astræa*, or star-

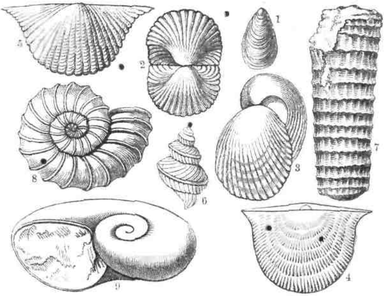


1, Cyathophyllum; 2, Favosites; 3, Astræa; 4, Heliolites; 5, Catenipora; 6, Cystidea; 7, Cyathocrinus (Taxocrinus).

coral; *heliolites*, or sun-coral; *favosites*, or honeycomb coral; *aulopora*, or pipe-pore coral; and *catenipora*, or chain-pore coral.

Indeed, so constant are the characters of these early and lowly organisms, that the palæontologist has as little difficulty in distinguishing a Silurian coral from an oolitic one, as he has in discriminating between the mollusca or crustacea of these distant epochs. Of the echinoderms, several well-marked groups are found in Silurian strata. The most abundant are the *Encrinites*, or lily-like radiata (*krinon*, a lily), whose calcareous skeletons often constitute the main mass of certain limestones, just as corals now constitute the chief mass of existing coral-reefs. Deferring further notice of the encrinite till we come to the carboniferous limestone, during the deposition of which the family seems to have attained its maximum development, we may simply mention that the Silurian genera are distinct from those of later formations, and are known by such names as the *cyathocrinus*, or cup-encrinite; *actinocrinus*, or prickly encrinite; *glyptocrinus*, or sculptured encrinite, and similar descriptive terms. Several star-fishes allied to the uraster and comatula of our own seas have also been detected; and these are known as *uraster*, *protaster* (*protos*, first—in allusion to its early appearance in geological formations), *lepidaster* (*lepis*, a scale), and the like. Among the echinoderms certain remarkable bladder-shaped forms have also been discovered; these are termed *cystideæ* (*cystus*, a bladder), and seem to approach the sea-urchins in structure. As an encrinite, with its numerous arms and feathery fingers, may be considered a star-fish fixed to the bottom by a jointed and flexible stalk, so may a cystidean, with its spherical body composed of numerous plates, be considered a sea-urchin attached to the bottom by a similar jointed column. Of these cystideans, the *apiocystites* (pear-shaped), *caryocystites* (clove-shaped), *prunocystites*, *hemicosmites*, and others, so named from their forms, are the most abundant and best known. Among the mollusca found in Silurian strata, there are the representatives of many existing orders—bivalves, allied to the cockle and pecten, others to the mussel; whorled univalves like the periwinkle; spirals like the pelican's-foot and tower-shell; chambered shells, coiled up like the pearly nautilus; and others, massive and straight, to which we have no existing analogues. In other words, and speaking technically, we have numerous species of the compound bryozoa, of the brachiopods, lamellibranchs, pteropods, gasteropods, and cephalopods. Among the most characteristic of the bryozoa we may mention *oldhamia*, *fenestella*, *retepora*, and *escharina*, all readily distinguished by their compound net-like arrangement; of the brachiopods perhaps *lingula*, *orthis*, *spirifera*, *atrypa*, *rhynconella*, and *pentamerus*, are the best known;

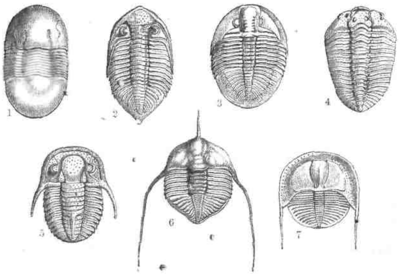
of the lamellibranchs, *avicula*, *inoceramus*, *posidonomya*, *arca*, *nucula*, and *modiola;* of the gasteropods, *euomphalus*, *murchisonia*, *trochus*, *pleurotomaria*, and *maclurea;* and of the cepha-



1, Lingula; 2, Rhynconella; 3, Pentamerus; 4, Strophomena; 5, Spirifer, 6, Murchisonia 7, Orthoceras; 8, Lituites; 9, Maclurea.

lopods, *lituites*, *orthoceras*, and *phragmoceras*. Among the annulose or worm-like impressions found in the system, there is considerable variety, and these have been generally attributed to true annelids. It is but fair to state, however, that many of the mollusca leave very peculiar trails or tracks on the soft mud over which they pass, that several of the minute crustaceans make long tortuous burrows in the sands, and that not a few of the so-called "serpulites," "nereites," &c., may be nothing more than casts or impressions of these primeval burrows and foot-trails. The subject is one still in great obscurity, though at present we rank provisionally under the head *Annelida* such organisms as *serpulites* (so called from their resemblance to the serpula of existing seas), *nereites*, *tentaculites*, *cornulites*, *crossopodia*, and the like; as well as the tubular casts of the burrows or bores of marine annelids like the lob-worm, and known as *arenicolites*, *foralites*, *scolites*, &c.; together with minute but well-defined species of true *spirorbes*. By far the most curious and abundant, as well as most characteristic of Silurian fossils, are the crustaceans termed "Trilobites," from the three-lobed-like figure of their

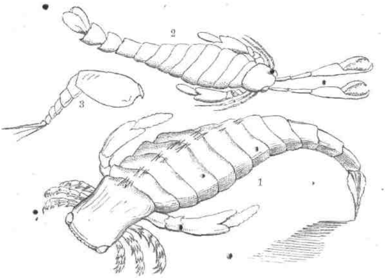
bodies. We have other entomostracous crustaceans, as the *hymenocaris*, *ceratiocaris*, *eurypterus*, and *pterygotus*, but by far the most typical development of the order lay in the trilobitidæ, whose genera and species of different form and ornamentation seemed to have swarmed in the Silurian waters, just as shrimps and prawns and crabs swarm in the seas of our own day. Many of them are extremely minute, and in all likelihood the larval forms of so-called genera; a considerable number (well known to collectors) attain a size of three or four inches; and it is rarely indeed that fragments are found indicating a length beyond twelve or fifteen inches. The most familiar forms of these trilobites are the *asaphus*, *ampyx*, *calymene*, *homalonotus*, *ogygia*, *olenus*, and



1, Illænus; 2, Phacops; 3, Ogygia; 4, Calymene; 5, Cyphaspis; 6, Ampyx; 7, Trinucleus

trinucleus; all of which consist of a cephalic shield or plate, furnished with prominent, many-facetted, sessile (or very rarely pedunculated) eyes, a three-lobed body in segments more or less numerous, and a caudal plate or appendage (*pygidium*) variously terminated. The names by which they are known refer in many instances to some peculiarity of form, as *trinucleus*; in others, as *asaphus* (obscure), *calymene* (concealed), &c., they refer to the obscurity which long rested, and still in some measure rests, on the real nature of these extinct creatures. First figured as an insect under the title of *Entomolithus paradoxus*, it was long before the affinities of the trilobite were determined; and even yet, with all that modern research has done, much of its true character, as

well as that of all the fossil crustacea, remains to be interpreted and determined. Higher than the trilobite there have been recently discovered in the upper Silurians of Lanarkshire and Herefordshire, several new genera and species of crustaceans which take rank under the fossil family *Eurypteridæ* (*euros*, breadth, and *pteron*, wing or fin, in allusion to their broad oar-like swimming limbs). The most abundant of these *Eurypterites* belong to the genera *pterygotus* and *eurypterus*, the individuals and species of which seem to have been extremely numerous, rivalling even the trilobite in the manner in which they appear to have thronged the muddy shallows of certain areas of the upper Silurian seashore. The distinguishing characteristics of the Eurypteridæ



1. Dorsal aspect of Pterygotus acuminatus; 2. P. bilobus; 3. Ceratiocaris (bivalved Entomostracan).—From the Upper Silurian or Passage Beds of Lanarkshire.

(several of which were first figured in this Text-Book) are, their long lobster-like forms, which consist (in the dorsal aspect) of an oblong-oval cephalo-thorax or carapace, with marginal or subcentral eyes; eleven abdominal or thoracico-abdominal segments, free and devoid of appendages; and a telson or tail-plate more or less elongated, and usually pointed. The carapace (in the oral or ventral aspect) is furnished with four or five pairs of five-jointed members—the three or four first variously formed in the different genera (some furnished with spines, others with prehensile pincers), and the posterior forming the broad swimming feet which give name to the family. The oral apparatus consists, as in the

king-crab, of the serrated basil joints of the limbs, and is protected by a broad heart-shaped metastome or mouthpiece. In all the genera the exterior crust is ornamented with a peculiar scale-like sculpture, which becomes bolder and stronger on the free or exposed margins.—[For further illustration, see par. 184, Old Red Sandstone.] As already stated, remains of *fishes* are found in the uppermost beds of the system, but these have been regarded by Sir Roderick Murchison as marking the dawn of the Devonian rather than the close of the Silurian era—"a long early period, in which no vertebrated animals had been called into existence." This opinion must be received, however, as indicating the paucity of such remains rather than their total absence; and for the final grouping of the "Tilestone" beds either as Silurian or Devonian, we must wait more extended research and the progress of discovery. As far as fossil evidence goes, in the mean time, they appear to be the legitimate base of the Devonian or Old Red Sandstone of Scotland; and, entertaining this opinion, we reserve description of their *fishes* and *peculiar crustaceans* till we come to treat of that system. We are no believers in artificial "systems" or sharply-defined "formations," nor would we encourage the idea that the creation of vertebrate existence in some of its forms was not coeval with that of the lowest invertebrata. On the contrary, all analogy favours the supposition that the great types of life—radiate, molluscan, articulate, and vertebrate—appeared simultaneously and independently on our globe; and that it is to the minor modifications of the type, and not to the type itself, we are to look for that gradation and progress which mark the successive geological epochs. The exposition of a science, however, requires various provisional aids and expedients; and merely as such and nothing more do we again warn the student to receive all the existing "systems" and "groups" and "series" of the working geologist.

Physical Aspects.

175. Respecting the extent of country occupied by Silurian strata, we have as yet no very accurate information. As before mentioned, they are most typically displayed in the district of country between England and Wales; the formation also occurs in a broad band along the entire south of Scotland, though not so clearly separable into series; and the lower portions appear also in Cumberland, Westmoreland, along the south-east coast

of Ireland, as well as in the western districts of Ross and Sutherland, in the Scottish Highlands. The system is found in Scandinavia, in Russia, and the Ourals, and very characteristically in Silesia and Bohemia. Silurian strata have also been investigated in the south of France, in Spain, in Asia Minor, in the Altai and Himalayan ranges, in China, in North and South Africa, in Australia, in North and South America, and also in the capes and islands of the Polar regions, and, as the progress of research advances, will no doubt be discovered in other regions. In all these districts the system is marked by the same peculiar fossils; and though the strata may differ very greatly in a mineralogical point of view—shales, for example, passing from soft disintegrating mudstones to hard fissile slates, sandstones passing from laminated sandstones to jaspery conglomerates, and limestones from calcareous marls to concretionary cornstones—still, the moment a geologist detects graptolites, trilobites, lingulæ, orthidæ, and the like, he can have no doubt as to his position among true Silurian strata.

176. The igneous rocks associated with the system are partly imbedded or contemporaneous, and partly eruptive. The imbedded traps are chiefly felspathic ash and tufa of a mixed mineral character, and have evidently been laid down in these primeval seas, sometimes in the state of overspreading or molten lava, and sometimes in the state of showers of scoriæ and ashes. The eruptive rocks are principally felspathic—felspathic greenstones, felspar rock, and felspar porphyry. In many instances, as in Wales and the south of Scotland, they have rendered the strata partially metamorphic, converting shales into good useful roofing-slates, sandstones into quartzite, and clays into hard jaspery hornstone. The upheavals and contortions resulting from their eruptions produce, on the whole, a varied and picturesque scenery, less abrupt and bold than that of primitive districts, yet more diversified by hill and dale, by ravine and river-glen, than that of later or secondary periods. "In Russia," says Sir Roderick Murchison, "the Silurian rocks form either wide level plains or low plateaux; whilst in other countries, where they have been heaved up into mountains, they have a rounded outline, especially where they consist of schists, originally composed of mud, the fine grains of which have given rise to equable atmospheric attrition. When, on the contrary, the shale and schist have been changed into hard slates, the sandstone into quartz rock, or the earthy limestone into crystalline marble, and particularly if the beds be highly inclined and

penetrated by igneous rocks, then sharp peaks or abrupt cliffs and gorges are dominant. Thus it is that the same ancient strata of different regions put on so many different external forms. In South Britain they are, necessarily, most varied in districts which, like those of North Wales and Cumberland, have had their outlines diversified by the intrusion of igneous rocks."

Industrial Products.

177. In an industrial point of view, the rocks of the Silurian system are of no great importance. Roofing-slate of various quality is obtained from the series, but of inferior value to that of the true clay-slate ; flagstones are quarried in some districts, though inferior to those of the old red sandstone ; freestone for building purposes is also a local product; and limestone for mortar and manure is quarried and burnt in most Silurian countries. The veins that traverse the system are in general metalliferous, and from these, ores of mercury, copper, lead, silver, and gold, are extracted. Indeed, according to Sir Roderick Murchison, "the most usual original position of gold is in quartzose veinstones that traverse altered palæozoic slates, frequently near their junction with eruptive rocks. Sometimes, however, it is also shown to be diffused through the body of such rocks, whether of igneous or of aqueous origin. The stratified rocks of the highest antiquity, such as the oldest gneiss or quartz rocks, have very seldom borne gold; but the sedimentary accumulations which followed, or the Silurian, Devonian, and Carboniferous (particularly the first of these three), have been the deposits which, in the tracts where they have undergone a metamorphosis or change of structure by the influence of igneous agency or other causes, have been the *chief* sources whence gold has been derived." This generalisation must be received, however, with some degree of caution, until we are enabled to define more clearly the limits of the vast formations—the so-called cambrians, the clay-slates, and chlorite slates—that lie between the fossiliferous silurians and the undoubted crystalline metamorphic strata.

NOTE, RECAPITULATORY AND EXPLANATORY.

178. In the preceding chapter we have presented an outline of the oldest or earliest fossiliferous strata as yet known to geologists. Originally designated the *Greywackè* or *Transition* formation, and but imperfectly defined and little understood, these strata have undergone during the last twenty years a most minute and careful survey, as regards both their palæontology and their order of superposition. They are largely developed in various countries, both in the Old and in the New World, and typically so in the district between England and Wales anciently inhabited by the Silures; hence the designation "SILURIAN SYSTEM" by Sir R. Murchison, their first and most ardent investigator. The system, though consisting, in the main, of alternations of flagstones and sandstones, of argillaceous and calcareous shales, of clayey limestones, and limestones of a concretionary structure, has been divided into *lower* and *upper* groups, and these groups again, in the typical district, into the *Llandeilo*, *Wenlock*, and *Ludlow* series. In the several series, abundant traces of invertebrate life have been detected, and numerous species of zoophytes, echinoderms, mollusca, annelida, and crustacea, figured and described—the higher crustacean forms belonging to the fossil family EURYPTERIDÆ. Remains of fishes have also been found in the upper beds, but these are regarded as marking the dawn of the Old Red Sandstone epoch, rather than as belonging to the close of the Silurian. Adhering to this view as a mere provisional line of distinction, we obtain a well-marked palæontological basis for the Old Red Sandstone, and can view the graptolites; the favosites and heliolites; the actiniocrinites, the marsupites, and cystideæ; the lingulæ, terebratulæ, and orthidæ; the lituites and orthoceratites; the serpulites and tentaculites; the asaphus, calymene, trinucleus, and other trilobites, as the peculiar and distinctive fauna of the silurian era. These creatures are all of true marine habitat, and, coupling this with the facts of ripple-mark, and with frequent alternations of shales, which were originally sea-silt; of sandstones, which point to sandy shores; of conglomerates, which speak of gravel beaches; and of limestones, that tell of shell-beds and coral reefs,—we are carried back through the lapse of ages to a series of seas and bays and estuaries, in which the operations of life and development went forward, deepening and spreading and multiplying, even as they do now.

179. Silurian strata seem to be extensively developed in most countries of the world, and, had the limits of an elementary treatise permitted, some important co-ordinations of the system, as exhibited in England, in Scotland, in Bohemia, Scandinavia, and North America, might have been attempted. As it is, it may be enough for the student to remember that the "Llandeilo," "Wenlock," and "Ludlow" series mark the ascending order in England; that the "Primordial," "Transition," and "Upper" zones indicate the same, or nearly so, in Bohemia; and that in North America, the "Champlain," "Ontario," and "Helderberg" divisions point to a similar, if not to a corresponding ascent. Wherever the co-ordination has been made, and "giving full weight" (we quote Professor Phillips) "to mineral as well as to organic associations, the reader cannot fail to be struck with the essential accordance between them all. We have always two great zones, which may be thus defined :—

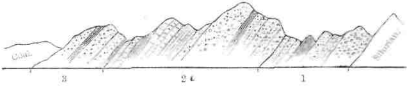
Upper Zone.—Contains limestones, and very numerous forms of invertebrate marine life—trilobites, orthocerata, phragmocerata, crinoidea, cystidea, zoantharia, &c.—Divisible into two parts; this is the original *Silurian system* of Murchison.

The two parts connected by a transition band (Llandovery rocks).

Lower Zone, without limestones, contains few forms of life, especially lingulæ, paradoxides, conocephalas, of *species* perhaps entirely, and of *genera* mostly distinct from those of the upper zone. This zone divisible into two parts; the upper having in certain portions a poor fauna, the lower *not yet* found to yield any forms of animal life. The upper part is the 'primordial zone' of M. Barrande; the lower part is the 'bottom zone' of the British Government Survey. Together they constitute what *was formerly understood*, or supposed to be the subject of Sedgwick's special inquiry in Wales, and called the *Cambrian system*."

180. To the student who feels desirous of entering more fully into the consideration of this interesting but partially understood system—and for all that has been done, there is not a wider or more attractive field for his research—we would recommend perusal of the following papers and monographs: The original *Silurian System* of Sir Roderick Murchison; *Siluria* (third edition), by the same author; the *Systême Silurien de Bohême* of M. Barrande; *Memoirs of the Geological Survey of Great Britain*, vol. i.; the papers of Professor Sedgwick in the *Transactions of the Geological Society;* Murchison's *Russia in Europe;* Mr James Hall's reports in the *Geological Survey of New York;* and Dr Bigsby *On the Palæozoic Rocks and Fossils of the State*

of New York, as given in the 14th volume of the *Quarterly Journal of the Geological Society*. To those more especially wishing to become familiar with the aspect of silurian fossils, the plates in the works of Murchison, Barrande, Hall, and in the Decades of the Geological Survey, will readily convey the desired information. The typical species (or those in the mean time erected into separate species) have also been arranged with more than usual care in the cases of the Jermyn Street Museum, London, and may be studied *en suite* as mapped on the Geological Survey of England.



XI.

OLD RED SANDSTONE OR DEVONIAN SYSTEM:

EMBRACING—1, THE LOWER; 2, THE MIDDLE; AND, 3, THE UPPER GROUPS OF BRITISH GEOLOGISTS.

181. TAKING the Coal-Measures as a sort of middle formation, there is generally found in the British Islands one set of reddish sandstones lying beneath, and another set lying immediately above them. By the earlier geologists the lower set was designated the *Old Red Sandstone*, and the upper the *New Red Sandstone;* and though the progress of the science has rendered it necessary to impose certain limitations on these terms, they are still sufficiently distinctive and easily remembered. The Old Red Sandstone may therefore be held as embracing the whole series of strata which lies between the silurian system on the one hand, and the carboniferous system on the other. Certain portions of the system are peculiarly developed in Devonshire, and contain a copious and varied fossil fauna; hence the introduction by Murchison and Sedgwick of the term *Devonian*—a term now generally employed as synonymous with the earlier and more descriptive one of "Old Red Sandstone." In the present chapter we shall use the term "Devonian" as applying more particularly to the strata as developed in the South of England, and the term "Old Red Sandstone" as more especially applicable to those of Scotland—believing, as we do, that the Caithness and Forfarshire beds are scarcely paralleled by the schists and limestones of Devonshire, and that it requires both developments to con-

stitute the "*system*" as at present understood by European and American geologists. In the area of Great Britain, indeed, there are several breaks between the various members of the system, which renders it somewhat difficult to co-relate and compare; but in the wider and unbroken areas of Russia and America, the whole are fused into one homogeneous Life-system, and to this—the whole range between Siluria and the Carboniferous rocks—the terms Old Red Sandstone or Devonian may be indiscriminately applied.

Lithological Composition.

182. The "Old Red Sandstone," as the name sufficiently indicates, consists of a succession of sandstones, alternating with subordinate layers of sandy shale and beds of concretionary limestones. The sandstones pass in fineness from close-grained fissile flags to thick beds of coarse conglomerate, and the shales from sandy laminated clay to soft flaky sandstone. The whole system is less or more coloured by the peroxide of iron—the shades varying from a dull rusty grey to a bright red, and from red to a fawn or cream-coloured yellow. Many of the shales are curiously mottled—green, purple, and yellow—and present an aspect which, once seen in the field, is not soon forgotten. On the whole, shades of red may be said to pervade the system, unless in some of the lower slaty bands, which present a dark and semi-bituminous aspect. The slaty bands of sandstone are locally known as *flagstones* and *tilestones;* the conglomerates, which are merely solidified gravel and shingle, are fancifully termed *puddingstones*—the pebbles being mingled through the mass like the fruit in a plum-pudding; and many of the limestones, from their siliceous or concretionary texture, are known by the name of *cornstones.* The shales are occasionally soft and friable, and in this state are by some termed *marls,* but as they contain no lime, the name is by no means appropriate. The "Devonian" proper, on the other hand, exhibits in its middle and upper portions an abundant development of fossiliferous limestones and calcareous shales, of slaty shales or dark bituminous-looking schists. Indeed, north of the Bristol Channel, the fossiliferous limestones, schists, and grits of Devonshire are altogether wanting; and we are thus warranted in regarding the red conglomerates, marls, and cornstones of Hereford and Monmouth, the red sandstones and conglomerates of Cumberland, the pebbly grits of Berwickshire, the yellow sandstones of Fife, the red sandstones and grey flags of

Forfar, the bouldery conglomerates that flank the Grampians, and the dark bituminous schists of Caithness, as portions of a formation somewhat older than the fossiliferous limestones and slaty shales of Devon, of Belgium, and central Europe, which seem to graduate into, and are in part inseparable from, the lower carboniferous strata. It is true that in Russia, and to some extent in North America, there appears to be an intimate interfusion of these two great divisions, hence the reason for regarding them, in the mean time, as one and the same system, and the terms "Old Red Sandstone" and "Devonian" as all but synonymous.

183. Proceeding downwards from the lowest beds of the carboniferous system, which are generally well defined by their abundant remains of calamites, stigmaria, sigillaria, sphenopteris, and other coal plants, the following may be taken as the order of the "Old Red" in the northern part of the British Islands:—

I. Yellow and Whitish Sandstones, generally fine-grained, but including detached pebbles, and alternating with layers of mottled shale. (Dura Den, Fifeshire.) *Characterised by abundant remains of holoptychius, glyptolepis, pterichthys, and other fishes; but by few plants.*
Coarse Pebbly Grits, alternating with whitish and chocolate-coloured sandstones. *Occasional scales of holoptychius,* numerous fucoids, and occasional land plants, as *Adiantites Hibernicus.* (Dunse and Denholm hill.)

II. Red Sandstones, generally in thick beds of a dull brick-red, enclosing detached pebbles of quartz and other rocks. Conglomerate beds apparently of littoral origin, layers of greenish, purple, and mottled shales, and beds of concretionary limestone or cornstone. This is the typical "Old Red" of Hereford, Cumberland, Fife, Perth, and Forfar. *Organic remains rather rare, and not very distinct, Holoptychius nobilissimus* being perhaps the most characteristic.

III. Dark Grey Micaceous Flagstones, with occasionally flaggy schists of a dark bituminous aspect (Caithness beds). *Characterised by abundant fish-remains, as coccosteus, asterolepis, osteolepis, dipterus, diplopterus, &c.; and by frequent but indistinct impressions of aquatic plants.*
Great Pebbly Conglomerate—a vast thickness of consolidated water-worn blocks and pebbles, with occasional interlaminations of fissile grey sandstone—stretches more or less persistently from Stonehaven on the east to Bute on the west, and developed also in Caithness and other localities. *No fossils.*

IV. Grey Rusty-coloured Sandstones, with enclosed pebbles and beds of conglomerate, subordinate to a vast thickness of fine-grained grey fissile flagstones and tilestones (Forfarshire, Perthshire, &c.) *Characterised by fish-remains, as cephalaspis, diplacanthus, climatius, acanthodes, ichthyodorulites, &c.; by pterygotus, eurypterus, stylonurus, and other crustacea; and by impressions of undetermined aquatic and land plants.*
Great Trappean Conglomerate—a peculiar aggregation of rounded pebbles and boulders (chiefly porphyries) cemented by trap-ash, and rarely interlaminated by grits or bands of sandstone. Flanks the southern Grampians from sea to sea.

The preceding synopsis represents the usual order of the system

as it occurs more particularly in Scotland, though few districts present an entire suit from the lowest to the highest strata. According to Phillips, the older red series of Wales and the course of the Wye and Severn may be thus expressed in general terms :—

UPPER GROUP.—*Conglomerates* and sandstones of red, purple, and green hue ; the pebbles, scattered in layers through masses of considerable thickness, are mostly of quartz, such as occurs abundantly in *veins* in the mica-schists and gneissose rocks. The magnitude of the pebbles varies from an inch or two across to small white grains. *Holoptychius nobilissimus* occurs in this series.

MIDDLE GROUP.—*Flagstone Series*, in great thickness, with partings of red shale, and some irregular calcareous cornstones. In the country about Milford Haven this series is usually traversed by nearly vertical slaty cleavage. Cephalaspis is met with in this series.

LOWER GROUP.—*Marl Series*, mostly red, with pale and greenish bands, and irregular cornstone layers. White, dark grey, and yellowish sandstones appear in the lower part of the series, especially round the May-hill district. (There is no coarse conglomerate in this part of the series comparable with that of the Cumbrian and Grampian chains.)

Such is Professor Phillips's grouping of the "Older Red" of England ; the following is Sir Roderick Murchison's co-ordination of the true Devonian with the Rhenish and Belgian types of the formation :—

Upper Devonian.—A series of schists characterised very extensively by the presence of a bivalvular crustacean (cypridina), and when limestones interlaminate the schist, by goniatites and clymenia. It prevails in Nassau, in Saxony, and Thuringia ; and may be paralleled by the Clymenian limestone of Petherwin, and the upper beds of North Devon. [*This series we are inclined to regard as lower carboniferous, and not Devonian.*]

Eifel Limestone.—The great central calcareous mass equivalent to that of Plymouth, and probably to that of Ilfracombe, full of corals, crinoidea, brachiopoda, gasteropoda, cephalopoda, and trilobites, and some of the old red fishes. *Stringocephalus Burtini* belongs to this rock.

Middle Devonian. — Schists with sandstones, and some impure limestones. *Calceola sandalina* belongs to this group.

Lower Devonian.—Sandstones with slaty schists and some impure limestone. This contains large spiriferæ, some species of phacops, and the curious *Pleurodictyum problematicum.*

According to Dr Bigsby, the following arrangement exhibits, in brief, the Devonian system of North America, and more especially as developed in the State of New York :—

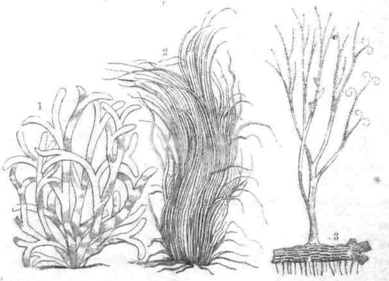
Stages.	*Sections.*	*Groups.*	*Prevailing Mineral.*
UPPER.	Old Red Sandstone.	V.	Conglomerate and Limestone.
MIDDLE.	Chemung Rocks. Portage Sandstone.	IV.	Argillaceous Sandstone.
	Genesee Slate. Tully Limestone. Hamilton Rocks. Marcellus Shales.	III.	Clay and Sandstone.

Stages.	*Sections.*	*Groups.*	*Prevailing Mineral.*
LOWER.	Corniferous Limestone. Onondago Limestone.	II.	Limestone.
	Schoharie Grit. Caudi-galli Grit. Oriskany Limestone.	I.	Sandstone.

On the whole, and without attempting minute co-ordinations for which we have not yet sufficient data, the system, as developed in Scotland, in Wales, Devonshire, Belgium, Russia, and North America, is sufficiently distinctive. Commencing with the flagstones or tilestones containing *onchus*, *cephalaspis*, and *pterygotus* — passing up through those imbedding *coccosteus*, *asterolepis*, and *dipterus*—and closing with those characterised by *Adiantites Hibernicus*, by *pterichthys*, *holoptychius*, *and other allied genera*—the "*cephalaspian*," "*dipteran*," and "*holoptychian*" zones are always sufficiently obvious in order of time; and serve in Britain, at least, as good finger-posts to guide the field geologist in his investigation of the Old Red Sandstone.

Palæontological Characteristics.

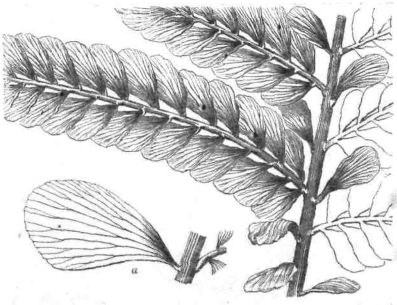
184. The organic remains of the system, though often not well preserved in consequence of the arenaceous nature of the rocks,



1, Fucoid (Roxburghshire); 2, Zosterites (Forfarshire); 3, Psilophyton (Canada).—Dawson.

are nevertheless of high and increasing interest, inasmuch as they

furnish abundant evidence of terrestrial vegetation, of new and higher forms of articulate life, and of vertebrate existence as manifested in the numerous and curious fishes of the period. As a whole, the system, in the area of Europe at least, is by no means fertile in PLANT remains, and even of such as do occur, the botanist has yet been unable to render any satisfactory interpretation. Among the tilestones and flagstones (Forfar and Caithness), as well as among the upper sandstones of the system (Roxburgh) we have impressions of *fuci* or sea-weeds (*chondrites*, *zosterites*, &c.), of marsh-plants, apparently allied to the equisetum, bulrush, and sedge (*juncites*), and of land plants akin to the tree-fern (*adiantites*), the *calamites*, and *lepidodendron* of the Coal-measures. Year after year these "lepidodendroid" stems are becoming better known, but so obscure are their external sculpturings as well as internal structure, that all we can do in the mean time is merely to indicate their affinity. On the whole, the Old Red flora of Europe occurs in a fragmentary and carbonised state, as if the plants had been drifted from a distance to the sea of deposit, and have as yet received but scanty attention from the fossil botanist. Among the flaggy shales of the Caithness

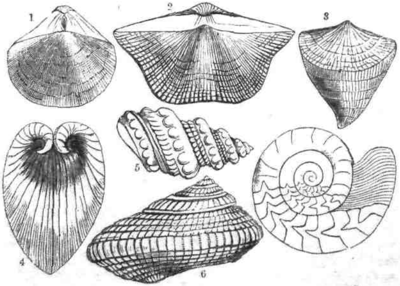


Adiantites Hibernicus; *a*, alternating pinnule.—Yellow Sandstone Series of Ireland and Roxburgh.

beds there occur dark bituminous bands, which have been assigned by some to a vegetable, and by others to an animal origin;

but the prevailing opinion now seems to be that the bituminous matter is the result of animal decay—of the vast shoals of fishes which were entombed in that muddy deposit. In some more favoured localities, however, like Point Gaspé, in Canada, thin seams of bituminous coal interlaminted with plant-yielding shales and sandstones have been discovered by Principal Dawson, thus giving new proof that, like other geological periods, the Old Red had its areas of fertility and areas of dwarfish sterility—regions where climatic influences were mild and genial, and others where they were rigorous and destructive of vegetation. Still, as a general truth, our knowledge of the Old Red Sandstone flora is limited and imperfect, and, with the exception of the large *laminarian*-like plants of Orkney, the *chondrites*, *zosterites*, *actinophyllum*, and other *fucoids* of the flagstones and upper sandstones; the beautiful *Adiantites Hibernicus*, and one or two *calamitoid* and *lepidodendroid* plants of the middle and upper groups, the vegetation of the period may be said to be wholly unknown to geology.

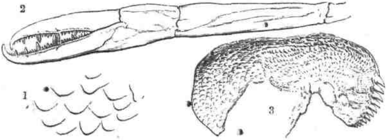
The FAUNA of the system, on the other hand, is much more abundant and better known, though it still requires much more minute elaboration than it has yet received. Among the zoo-



1, Stringocephalus; 2, Spirifera; 3, Calceola; 4, Megalodon; 5, Murchisonia, 6, Pleurotomaria; 7, Clymenia.

phytes we have various species of *arachnophyllum*, *cyathophyllum*, *cystiphyllum*, *favosites*, *heliolites*, and other corals differing little

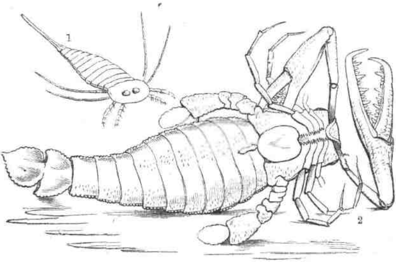
from those of Siluria; and in the upper groups a few crinoid and cystoid echinoderms, as *actinocrinus*, *cyathocrinus*, *cupressocrinus*, and *echinosphærites*. Of the Mollusca we have several compound forms (bryozoa), as *fenestella* and *retepora;* of brachiopods, *atrypa*, *calceola*, *orthis*, *spirifera*, *terebratula*, and *stringocephalus;* of lamellibranch bivalves, *avicula*, *corbula*, *megalodon*, *modiola*, and *anodon;* of gasteropods, *euomphalus*, *murchisonia*, and *pleurotomaria;* and of chambered cephalopods, *clymenia*, *goniatites*, and *orthoceras* are the most characteristic. We have also a number of annelid tracks and burrows—the former winding in great profusion over the surfaces of many of the lower flagstones, and the latter piercing the same strata often to the depth of twelve or eighteen inches, and not unfrequently one or two inches in diameter, thus showing the gigantic size of these unknown burrowers. Among the Crustacea we have still a few of silurian forms—the *calymene*, *homalonotus*, and *cheirurus;* but the meridian of trilobite life is evidently passed, and we have now the *cypridina*, the *bronteus*, the *ceratiocaris*, *kampecaris*, *pterygotus*, *eurypterus*, *stylonurus*, and other forms peculiar to the period. These crustaceans, and their recent discovery, form altogether an interesting chapter in palæontology.



1. Scale-like sculpture of Pterygotus; 2. Pincers of prehensible limb; 3. Jaw-foot and basal joint of swimming limb.

The mandibular or jaw-feet of pterygotus, known for the last fifty years to the quarrymen of Forfar by the title of "seraphim" (from a fanciful resemblance to the wings of the sculptured seraphim), were first mistaken by Agassiz for the remains of fishes; hence the name pterygotus (from *pteryx*, a wing, and *ous*, *otos*, an ear), in allusion to the peculiar configuration of these jaw-feet. On inspection of the Balruddery collection (now unluckily dispersed), M. Agassiz at once discovered the crustacean affinities of these remains, and termed the creature to which they belonged *Palæocarcinus alatus*—a far more appropriate name, but one scarcely, if at all, known to British palæontologists. When exa-

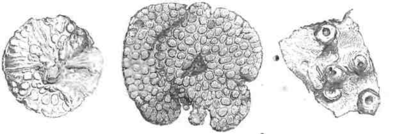
mined by Agassiz in 1844 the data were too imperfect for an attempted restoration, but now, what with new facts and the discovery of allied genera, we are enabled to restore in outline the great *Pterygotus* of Forfarshire (for there are several species) with



1. Stylonurus Powriei; 2. Pterygotus Anglicus, ventral or oral aspect, showing the serrated foot-jaws, heart-shaped metastome, and ventral orifice on the first thoracico-abdominal segment. From the Lower Old Red of Forfarshire.

something like certainty, and to arrive at the conclusion that many of the larger specimens attained a length of four, five, and six feet, with a corresponding increase in their other dimensions. Since the dispersion of Mr Webster's collection other crustacean forms have been discovered by the author of this treatise, in the Forfarshire flagstones; by Mr Slimon, in the mudstones of upper Lanarkshire, which may be regarded as the capping of the Upper Silurian; by Mr Banks, in the Kington tilestones of Hereford; and more recently by Mr Powrie of Reswallie, in the grey tilestones near Forfar. These crustaceans are so peculiar—exhibiting a sort of compound structure partly phyllopod, partly pœcilipod, partly macrurus, and partly xiphosurus—that in an elementary work it would be out of place to allude to them, further than merely to remark, as the author did at the British Association in 1855, that they seem to indicate a great zone of crustacean life on the lowest verge of the Old Red Sandstone period. Whether this zone shall be ultimately ranked as Lower Devonian, as Upper Silurian, or as the "passage beds" between the two systems, must altogether depend on fossil evidence; and in the mean time we

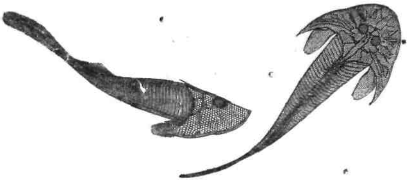
are not in a position to do more than merely announce the fact that, somewhere about this stage in the ascending scale of time, we have a strange and varied development of crustacean life hitherto unknown to Palæontology. The epoch of the Trilobite is on the wane, and higher and more complex forms betoken the dawn of another palæozoic period, the biological peculiarities of which Geology has yet to interpret. (See Recapitulation.) Another curious feature in connection with these crustacea, and occurring in the same beds, is an immense number of dark-coloured patches of spawn-like organisms, which are now pretty generally regarded as the egg-packets of eurypterus and pterygotus. Compressed and flattened, the ova appear less or more



Parka Decipiens—Supposed Spawn or Egg-packets of Crustacea.

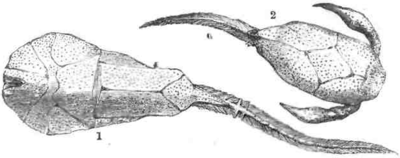
in concentric arrangement, and every appearance favours the idea of their crustacean origin, unless, perhaps, their great abundance, which has suggested to some the possibility of their being the berries or carpels of some unknown plant. The egg-packet theory is now the most prevalent; and, admitting its truth, the wide-spread abundance of these remains increases beyond expression our notions of the exuberance of crustacean life within certain areas of the old red sandstone. The Fishes of the period are also peculiar, inasmuch as many of them are covered with bony plates, or with hard enamelled scales; are frequently furnished with fin-spines, or external defences; and are many of them of forms widely different from the fishes of existing seas. In many cases we have only a scale or fragment of bone (an *ichthyolite*) to guide us in our determinations; and in others detached fin-spines, known to the palæontologist as *ichthyodorulites* (from *ichthys*, a fish, *doru*, a spear, and *lithos*, a stone). Of the more characteristic fishes of the period, we may notice the *cephalaspis*, or buckler-head (*kephalè*, the head, and *aspis*, a buckler), so named from the shield-like shape of its head; the *coccosteus* or berry-bone (*kokkos*, a berry, and *osteon*, a bone), so called from the berry-like tuber-

cles which stud its bony plates; the *pterichthys*, or wing-fish, (*pteron*, a wing, and *ichthys*, a fish), which receives its name from



Cephalaspis Lyelli—(From specimens in possession of Mr Powrie and the Author.)

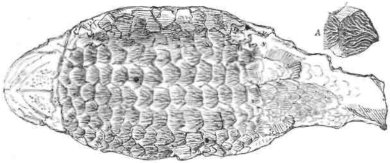
the peculiar wing-like appendages attached to its body; the *holoptychius*, or all wrinkle (*holos*, entire, and *ptychè*, a wrinkle), so termed from the wrinkled surface of its large enamelled scales; asterolepis or star-scale (*asteron*, a star, and *lepis*, a scale); *osteolepis* or bone-scale (*osteon*, a bone); *dipterus*, or double-fin; *diplacanthus*, or double-spine, and so forth—all of them receiving their names from some marked and peculiar external feature. These fishes seem, to have thronged the waters of



1, Coccosteus cuspidatus; 2, Pterichthys Milleri.

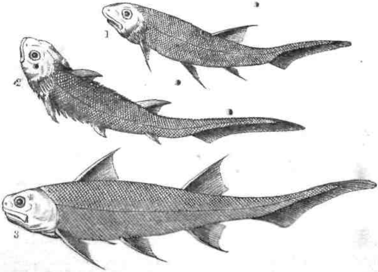
the period, and their remains are often found in masses, as if they had been suddenly entombed in living shoals by the sediment which now contains them. Occasionally only detached scales are found, as if these had been drifted about on the shores of deposit, and at other times a spine is all that bears evidence of their existence. To these spines the palæontologist, in the mean time, assigns distinct *generic* names, though it may hereafter turn out that the spines of the different fins on the same fish may have

been differently armed and ornamented, and also of different shapes—the dorsals differing from the sub-dorsals, and these again



Holoptychius Nobilissimus (Perthshire). A, detached scale.

from the pectorals. Of course, in this, as in other instances, there is much that is merely provisional, and awaits the corroboration or correction of future discovery; and knowing so, we feel it our duty here to tell the student plainly and without reserve, that notwithstanding all that has been written and said about the fishes of the old red sandstone, they are still very imperfectly



1, Cheiracanthus; 2, Climatius; 3, Diplacanthus (Forfarshire).

known. Though attempting an outline restoration of the cephalaspis, we yet know nothing of its mouth or dentition; we have still less knowledge of the coccosteus; while the osteology and

presumable functions of the pterichthys is a problem yet to be solved by the palæontologist. Turning next to the higher order of Reptiles, we have as yet no undoubted instance of their existence, though footprints, bones, and scutes, unquestionably reptilian, have been detected in the sandstones of Elgin — sandstones till recently regarded as Devonian, but whose relations have lately been questioned ; *first*, on account of the obscurity of their stratigraphical relations to the surrounding old red sandstone of the district ; and, *second*, on account of the affinity of their reptilian remains to those occurring in true triassic strata. Partaking in the doubt, both on lithological and palæontological grounds, that the place of these Elgin sandstones may yet be found to belong to the dawn of the Triassic, and not to the close of the Devonian, epoch, we have transferred the small lizard-like *telerpeton*, and the large "drop-scaled" crocodilian *staganolepis*, to the newer era—a transposition already approved by some of our leading palæontologists. It is thus that palæontology often corrects the first impressions of physical geology, and in this instance conformably so with all that we know of the reptilian life of the carboniferous era, where forms more lowly and fish-like in their character alone make their appearance. In the mean time, therefore, the existence of reptiles during the Old Red Sandstone epoch must be held as problematical, and palæontology constrained to date their advent with the commencement of the carboniferous era. If it shall be ultimately found that these Elgin sandstones are of true Devonian age, the occurrence of reptiles having such high affinities as lizards and crocodiles will once more correct the hasty generalisations of limited observation, and teach us how vain it is to dogmatise on the rise and order of life from the imperfect data which geology has yet at her command.

Physical Aspects.

185. The igneous rocks more intimately associated with the system are greenstone, clinkstone, compact felspar, felspar-porphyry, claystone-porphyry, amygdaloid, and other varieties of felspathic trap. Unless in the lower group, these traps are rarely interstratified with the sandstones, and in this respect present a striking difference from the tufas and ashes which often alternate with the strata of the silurian and lower carboniferous systems. They occur chiefly as upheaving and disrupt-

ing masses, and are themselves frequently cut through by later dykes of greenstone, felspar, and porphyry—thus seemingly indicating a cessation of volcanic action during the main deposition of the old red sandstone, but a period of great activity and disturbance both at its commencement and at its close. Granitic outbursts are rare in connection with the Old Red; and it may be received as a great fact that the period of the granite had given way to that of the trap, with its multifarious compounds.

186. The physical features of old red sandstone districts in Great Britain are generally highly diversified and irregular—the hills being less bold and precipitous than those of primitive districts, and more lofty and irregular than those of the later secondaries. Where the strata are unbroken by trap eruptions the scenery is rather flat and tame; but the soil is light and fertile, being based on sand, gravel, and friable clays, the ancient debris of the formation. On the other hand, the hills of old red districts present great diversity of scenery; here rising in rounded heights, there sinking in easy undulations; now swelling in sunny slopes, and anon retiring in winding glens or rounded valley-basins of great beauty and fertility. The Ochils and Sidlaws in Scotland, with their intervening valleys, and the hills of Hereford, Brecknock, and Monmouth, in England, belong exclusively to this formation, and may be taken as the type of its physical features.

187. The geographical distribution of the old red sandstone is very extensive, and there are few regions in which one or other of its groups is not clearly developed. In the eastern counties of Scotland, all the groups of the system are well exposed; the lower portions occur largely in South Wales and Devon, in the south of Ireland, in Belgium, and in Germany; the middle portions occupy extensive areas in Russia and the flats of Central Europe, in Siberia and Tartary, on to the flanks of the Himalaya Mountains; and different members of the system are found in Central and Southern Africa, in the United States and Canada, and the Brazils. Wherever the system occurs, its strata give ample evidence of oceanic conditions—of deep and tranquil seas, in which were deposited the frequent alternations of the flagstones and tilestones; of sandy shores, where the thick beds of sandstones were collected and arranged; and of gravel beaches, which were cemented and solidified into conglomerates and puddingstones. Touching these conglomerates, it is but right to inform the student, that while most of them seem to be of *littoral* origin, others are so peculiar in their com-

position—some of the blocks being boulders rather than pebbles—and so irregularly arranged in the mass of finer sediment, that their formation can scarcely be accounted for by the ordinary operations of the sea-shore. The agency of ice, to transport and accumulate, has accordingly been suggested ; and on the whole, without calling in the presence of some such power, it seems impossible to account for the heterogeneous aggregation of masses like the so-called "great conglomerate" of Scotland. During the great progressional cycles of nature, a glacial climate over certain areas now occupied by the Old Red Sandstone is quite as comprehensible, as one during the formation of the English "Permian breccias" (which see), or during the accumulation of the "Boulder drift," which immediately preceded the existing conditions of the northern hemisphere. Again, the frequent ripple-marks on the old red sandstone speak of receding tides and ocean-currents ; the indentations left by rain-drops tell of heavy showers ; the abundance of zoophytes, shell-fish, crustacea, and fishes, testifies to the exuberance of marine life, at least in certain localities ; and the foot-tracks and skeletons of reptiles (if the Elgin sandstones should be ultimately proved to be of Devonian age) would indicate in like manner the presence of terrestrial existence. And if we turn to the vegetable remains, we find in them, scanty as they may appear, sufficient evidence of marsh, and plain, and hill-side, of rains to nourish, and rivers to transport.

Industrial Products.

188. Economically, the products of the Old Red Sandstone system are neither very numerous nor of prime importance. From the fissile or laminated beds are obtained such flagstones as those of Forfar and Caithness, so extensively used in paving and shelving ; and from the same group are raised those "grey slates" or tilestones, at one time so generally, and still to some extent, employed in roofing. Building-stone is also obtained from the thick-bedded sandstones ; but in general the freestones of the system, whether red, grey, or yellow, are not in great repute, either for their beauty or durability. Limestone for building and agriculture is obtained from the cornstones ; and besides these uses, some of the Devonshire limestones, as those near Torquay, furnish not only durable building-stones, but frequently not indifferent marbles. The felspars, porphyries, and greenstones are

exceedingly durable, but are seldom used in building, owing to the difficulty of dressing them into form. They make first-rate road materials, however, and for this purpose are largely employed in the districts where they occur. To the traps of the Old Red the lapidary is chiefly indebted for most of the agates, jaspers, carnelians, and chalcedonies, known as "Scotch pebbles" —these gems being usually found in rough-looking nodules among the debris of the disintegrated rocks, or extracted from the soft exposed amygdaloids, as along the Usan coast near Montrose. The most important brine-springs in the United States and British North America are situated on the Devonian formation—and from those of Onondago alone, in 1859, within a fraction of 7,000,000 bushels of salt were prepared, partly by boiling and partly by solar evaporation.

NOTE, RECAPITULATORY AND EXPLANATORY.

189. The system which we have now reviewed under the term of the OLD RED SANDSTONE or DEVONIAN, is one of the most remarkable and clearly defined in the crust of the globe. Characterised on its lower margin by strata containing the remains of fishes, and which form a line of separation, as it were, between it and the underlying Silurian, and defined, on its upper margin, by the rarity of that vegetation which enters so profusely into the composition of the Carboniferous rocks, there can, in general, be no difficulty in determining the limits of the Old Red formation. On the whole, its composition is manifestly arenaceous, the great bulk of the system being made up of sandstones and conglomerates, with subordinate strata of shales and concretionary limestones. Though yielding numerous plant-impressions and remains of zoophytes, mollusca, and peculiar crustaceans, its most marked and characteristic fossils are *fishes*, often of peculiar forms, and covered with hard enamelled scales, or encased in bony plates, and not unfrequently armed with sharp defensive fin-spines. The igneous rocks connected with the system are greenstones, clinkstones, claystones, felspars, porphyries, and other varieties of felspathic traps. These traps are rarely interstratified with the sandstones, and generally appear as disrupting and upheaving masses, either about the commencement or at the close of the period when those hills and ranges were formed which confer on

Old Red districts their peculiarly undulating and diversified scenery. Looking at the whole system, both in point of time and composition, we are prominently reminded of marine conditions—of sea-shores whose sands formed sandstones, and of beaches whose gravel was consolidated into conglomerates and puddingstone—of receding tides that produced ripple-marks, and of showers that left their impressions on the half-dried silt of muddy estuaries. The reddish colour which pervades the whole strata shows that the waters of deposit must have been largely impregnated with iron—in all probability derived from the earlier granitic and metamorphic rocks, whose degradation supplied the sands and gravels of the system. If, on the other hand, we investigate the fossil remains, we are reminded of placid waters where zoophytes and mollusca swarmed in profusion; of disturbances which entombed whole shoals of fishes in marine sediment; of marshes and river-banks which gave birth to a scanty growth of ferns, reeds, and rush-like vegetables; and of sedgy margins, where, perhaps, a few lowly reptiles enjoyed the necessary conditions of an amphibious existence.

190. We have already alluded to the difficulty of co-ordinating the vast suite of strata usually embraced by geologists under the terms "Devonian" and "Old Red Sandstone." The time has not yet arrived for establishing *equivalents* in distant regions, such as Britain, continental Europe, and North America; but taking the system as separable into three great groups, and throwing aside the cypridina slates of Belgium and the Petherwin beds of North Devon as lower carboniferous, the following may be received as an approximation:—

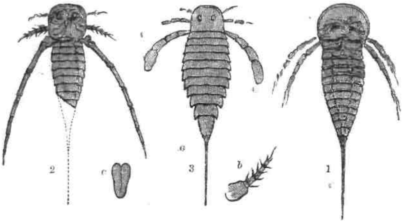
UPPER.	Baggy Point sandstone and Morte Bay schists, N. Devon; goniatite limestone, Belgium; yellow sandstones of Dura Den, Fife; Telerpeton beds, Elgin; Cyclopteris beds of Kilkenny; red and white sandstones of Dunse.
MIDDLE.	Ilfracombe and Plymouth limestones, Devon; Eifel limestone, Belgium; red sandstones of Berwick and Roxburgh; red sandstones, marls, conglomerates, and cornstones of Hereford, Cumberland, Fife, Perth, and Forfar.
LOWER.	Caithness flags and shales; N. Foreland, Porlock, and Torquay beds, Devon; Spirifer sandstones and shale, Rhine; great pebbly conglomerates and flagstones of Forfar; Ludlow and Lanark Tilestones.

In placing these "Tilestones" at the base of the system, it is but fair to inform the student that they are classed by some geologists as Devonian, and by others as Silurian. The truth is, they form a sort of neutral ground or "Passage Beds" between the two systems; and the progress of the science can be little retarded by

regarding them in either light? It is impossible in every case to draw sharp lines of demarcation between our so-called series and systems; and to insist upon such boundaries is often to do violence to fact and obstruct discovery. In the mean time we regard the Ludlow and Lanark "Tilestones" as Upper Silurian, because associated with them we have *lingula, trochus, pterinea, avicula, orthoceras*, and other silurian shells, and no authenticated instance of *cephalaspis* occurring along with them; and we retain as the true and natural basis of the Old Red, the "flagstones" of Forfar and Perth, because, associated with the crustaceans common to both series, we find in them abundant remains of *cephalaspis, acanthodes, diplacanthus, climatius*, and other fishes admittedly Devonian; and, lastly, because the great physical sections are much more naturally co-related to the one system than to the other. But, whether Devonian or Silurian, there can be no doubt that these Forfar, Lanark, and Ludlow beds constitute a great zone of crustacean life altogether distinct and peculiar, and which is only beginning to reveal its treasures to the science of palæontology.

191. Respecting these crustaceans we may briefly remark, that their place is altogether unknown in zoology. The living crustacea are by no means a well-understood class—the difficulty being increased by the fact that many genera are totally unlike in their larval and adult conditions, and that most of them pass through several stages of metamorphosis. Much more apparently does this difficulty present itself among these palæozoic crustacea—there being, as it were, an interfusion of phyllopod, pœcilipod, and decapod—of brachyurus, macrurus, and xiphosurus forms. Besides several species of *pterygotus*, with their huge prehensile claws, and swimming paddles, and scale-like sculptured segments, which often indicate individuals four and six feet in length, we have the *ceratiocaris*, a shrimp-like form (*ceration*, a pod, *caris*, a shrimp), so called from the pod-like shape of its bivalve shield; the *kampecaris*, a diminutive form (*kampè*, a grub or caterpillar), named from its caterpillar-like appearance, and occurring in shoals in the Forfarshire flags; the cumoid forms found so abundantly in the mudstones of Upper Lanark, and already noticed under the preceding system (par. 174); the *eurypteri* found in the passage beds of Russia as well as in those of Ludlow and Forfar; and the still more complex form of *stylonurus*, first obtained by Mr Powrie from the tilestones of Forfar, and so named from the peculiar style-like form of its caudal appendage, but subsequently also from the mudstones of Lanark. All these,

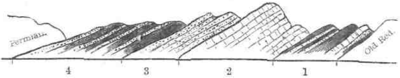
and other forms yet undescribed, are comparatively new to science; are here (most of them) for the first time figured; and open up,



1, Stylonurus Powriei (Forfar); 2, S. spinipes (Lanark); *a*, metastome of do., *b*, spiny palp; 3, Eurypterus clavipes (Russia), Eichwald.

as we have already said, a fresh and inviting field to the crustaceologist.

192. For further elucidation of this classical system, the student may refer to Hugh Miller's *Old Red Sandstone;* to the *Poissons Fossiles* and *Monographie des Poissons Fossiles du Vieux Grès Rouge* of Agassiz; to several of the chapters in Murchison's *Siluria;* to De La Beche's *Report on the Geology of Devon;* to Murchison's *Russia in Europe;* and to several recent papers by various observers in the *Journal of the Geological Society.*



XII.

THE CARBONIFEROUS SYSTEM:

EMBRACING—1, THE LOWER COAL-MEASURES; 2, THE MOUNTAIN *LIMESTONE; AND,* 3, 4, *THE MILLSTONE GRIT* AND UPPER OR TRUE COAL-MEASURES.

193. IMMEDIATELY above the Old Red Sandstone or Devonian strata, but clearly distinguished from them by the abundance of their vegetable remains, occur the lower members of the CARBONIFEROUS SYSTEM. It is to this profusion of vegetable matter —the chief solid element of which is carbon—that the system owes its name; a profusion which has formed beds of coal (coal being but a mass of mineralised vegetation), enters into the composition of all the bituminous or coaly shales, and which stamps many of the sandstones and limestones of the formation with a carbonaceous aspect. As above indicated, the system is generally separable into three well-marked groups—*the lower coal-measures,* or *carboniferous slates; the mountain limestone;* and the *upper* or *true coal-measures.* The student must not, however, suppose that these groups are everywhere present one above another in regular order. All that is affirmed by geology is, that these three groups are found in certain localities (Nova Scotia and Scotland, for example); and it is a rule of the science always to take as the type of a formation the fullest development that can be discovered. In some districts, as in the north of England, the carboniferous slates are absent, and the mountain limestone with its shales rests immediately on the old red sandstone; in other countries both the lower groups are absent, and the coal reposes

on old crystalline rocks; while, on the other hand, in Ireland the carboniferous slates and mountain limestone are enormously developed, and the coal-measures very sparingly and partially so. Whatever portion of the system may be present, it is always easily recognised—the abundance and peculiarity of its fossil vegetables impressing it with features which, once seen, can never be mistaken for those of any other formation. Derived from the waste of all the preceding rocks—the granitic, metamorphic, silurian, and old red sandstone—the strata of the system necessarily present a great variety and complexity of composition. There are sandstones of every degree of purity, from thick beds composed of white quartz grains, to flaggy strata differing little from sandy shales; shales from soft laminated clays to dark slaty flags, and from these to beds so bituminous that they are scarcely distinguishable from impure coals; and limestones, from sparkling saccharoid marbles to calcareous grits and shales. Besides these varieties of sandstones, clays, shales, and limestones, there occur, for the first time on a notable scale, seams of *bituminous coal* and bands of *ironstone*, and these also, appearing in every degree of admixture, add still further to the complexity of the system. On the whole, the carboniferous strata, from first to last, may be said to be composed of frequent alternations of sandstones, shales, limestones, coals, and ironstones—and these in their respective groups we shall now consider.

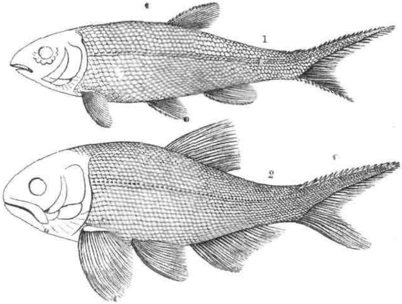
I.—LOWER COAL-MEASURES, OR CARBONIFEROUS SLATES.

194. This group is meant to embrace all the alternations of strata which lie between the old red sandstone and the mountain or carboniferous limestone. In some districts it is very scantily developed; in others, as in Ireland and Scotland, it attains a thickness of several thousand feet. In the south of Ireland it consists chiefly of dark slaty shales, grits, flaggy limestones, and thin seams of impure coal; and has, from the general slaty aspect of its strata, been termed by Sir R. Griffiths the *Carboniferous Slates*. In Scotland, particularly in the east of Fife and the Lothians, it has none of this slaty character, but consists essentially of thick-bedded white sandstones, dark bituminous shales, frequently imbedding bands of ironstone, thin seams of coal, and peculiar strata, either of shell-limestone or of argillaceous limestone, thought from its fossils to be of fresh-water or estuary origin. Unless in its fine white sandstones (the ordinary build-

ing-stone of Edinburgh and St Andrews), in its fine-grained estuary and shell limestones (Burdiehouse and Burntisland), and in the greater profusion of its shells and fishes, the lower group, as developed in Scotland, differs little in appearance from the upper group; hence the term *Lower Coal-Measures* generally applied to it in that country. In Nova Scotia, as shown by Mr Dawson, the lower carboniferous measures consist chiefly of clayey and bituminous shales, sandstones, and thick beds of gypsum; and as a group are clearly separable from the true coal-measures above, both in their lithological and palæontological aspects.

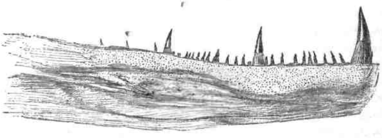
195. Looking at the lower coal-measures in the mass, there cannot be a doubt they were deposited under very different conditions from the old red sandstone beneath, and the mountain limestone above. Both these formations are eminently marine—the yellow sandstones being replete with true oceanic fishes, and the mountain limestone profusely charged with marine shells and corals. The lower coal-measures, on the other hand, have more of a fresh-water than of a salt-water aspect. Coralloid fossils are rarely or ever found in their strata; their shells are, for the most part, estuarine; their plants seem to have grown in marshes and delta-jungles, and many of their fishes are large and of sauroid types. Under these circumstances, we are justified in regarding them as a separate group—a group which, when more minutely investigated as to the specific characters of its fossils, will throw much important light on the earlier history of the period. In this opinion (advanced in 1840) we are more and more confirmed by the researches of Continental and American geologists, who are also beginning to draw a line of distinction between the Upper and Lower coal groups, and to detect specific differences in the plants of the two horizons. As a whole, the lower coal group in Scotland is eminently characterised by fresh-water or estuary remains, though in several instances bands of limestone and ironstone occur containing encrinal joints, retepora, palæchinus, Murchisonia, and the like; thus showing that during the deposition of the strata there were occasional alternations of marine and fresh-water conditions. The PLANTS most characteristic of the group are *sphenopteris affinis, s. bifida,* and *s. linearis; pecopteris heterophyllum; neuropteris Loshii; calamites cannæformis; lepidodendron elegans, l. selaginoides,* and *l. gracilis; lepidostrobus variabilis* and *ornatus; lepidophyllum intermedium; stigmaria ficoides* and *stellata;* with *sigillaria pachyderma* and *oculata, Knorria* of various species, and *favularia.* Of the ANIMAL remains the most characteristic are the minute crusta-

ceans *cypris Scoto-burdigalensis* and *Hibbertii*, which abound in all the shales and limestones ; *microconchus carbonarius*, or *spirorbis;* various *unionidæ* (*anthracosiæ ?*), sometimes forming whole



1, Palæoniscus ornatissimus; 2, Amblypterus nemopterus.

bands of shell-limestone ; *palæoniscus Robisonii*, *eurynotus*, *amblypterus*, and *platysomus ; megalichthys*, *rhizodus Hibbertii*, and



Jaw and dentition of Rhizodus Hibbertii—Sauroid fish.

some other well-marked ichthyolites and coprolites yet unfigured and undescribed. So characteristic, indeed, are many of these fossils, that there is little difficulty in determining, by their aid, the lower from the upper coal-measures.

196. In its mineral composition and structure, the group bears evidence of frequent alternations of sediment, as if the rivers of transport were now charged with mud and vegetable debris, now with limy silt, and anon with sand and clay. There are no con-

glomerates as in the old red sandstone, and from the laminated structure of most of the strata, they seem to have been deposited in tranquil waters. There are, however, more frequent interstratifications of igneous rock and precipitated showers of volcanic ash, as if the seas and estuaries of deposit had also been the seats of submarine volcanoes and craters of eruption. The iron which impregnated the waters of the old red period, and tinged with rusty red the whole of that system, now appears in the segregated form of thin layers and bands of ironstone. The frequent thin seams of coal point to a new exuberance of terrestrial vegetation, and indicate the existence of a genial climate and of dry lands—of upland forests where pines like the araucaria reared their gigantic trunks—of river-banks where tree-ferns waved their feathery fronds—and of estuary swamps where gigantic reeds, equisetums, and other marsh vegetation, flourished in abundance. On the whole, the evidence of *drifting* agencies is much more apparent in the coals of the Lower than in those of the Upper series. Interlaminated bands of mud and ironstone, shells, fish-spines, and other detached organisms imbedded in the coal, as well as the general absence of true "under-clays" or ancient soils of growth, point to conditions of drift and estuary accumulation, rather than to terrestrial growth *in situ* and subsequent submergence (*see* Recapitulation). Again, when we turn to the shell-limestones, and find them two or three feet in thickness (Kingsbarns, Fifeshire), and entirely composed of mussel-like bivalves (*anodon*, *anthracosia*, &c.), we are instantly reminded of estuaries where these shell-fish lived in beds, as do the mussel and other gregarious molluscs of the present day. Or if we examine the frequent remains of the fishes which are found in the shales and limestones, we have ample evidence of their predaceous habits, and are forcibly reminded of shallow seas and estuaries, where huge sauroid fishes were the tyrant-scavengers of the period. A few fragments of land-shells, and the skeletons of some minute reptiles apparently allied to the batrachians or frog-kind, indicate the existence of a terrestrial fauna which becomes more abundant and varied in the higher groups of the system.

II.—MOUNTAIN OR CARBONIFEROUS LIMESTONE.

197. This group is one of the most distinct and unmistakable in the whole crust of the earth. Whether consisting of one thick reef-like bed of limestone, or of many beds with alternating shales and gritty sandstones, its peculiar corals, encrinites,

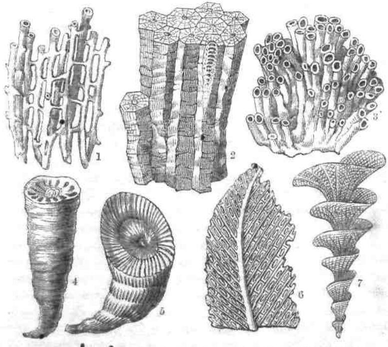
and shells distinguish it at once from all other series of strata. In fact, it forms in the rocky crust a zone, so marked and peculiar, that it becomes a guiding post, not only to the miner in the carboniferous system, but to the geologist in his researches among other strata. It has received the name of *Mountain Limestone* because it is very generally found flanking or crowning the trap-hills that intervene between the Old Red and the Coal-measures, where, from its hard and durable texture, it forms bold escarpments, as in the hills of Derbyshire, Yorkshire, Westmoreland, Fife, and many parts of Ireland. It is also termed the *Carboniferous Limestone*, from its occurring in that system, and constituting one of its most remarkable features.

198. As already indicated, this group in some districts consists of a few thick beds of limestone, with subordinate layers of calcareous shale. In other localities the shales predominate, and the limestones occupy a subordinate place alternating with the shales, thin seams of coal, and strata of gritty sandstones. Occasionally the limestone appears in one bold reef-like mass, of several hundred feet in thickness, separated by a few partings of shale, or rather layers of impure limestone. Whatever be the order of succession, it usually occurs as a dark sub-crystalline limestone, occasionally used as marble, but more frequently raised for mortar, for iron-smelting, and for agricultural purposes. Along with the other members of the group, it is often replete with the exuviæ of corals, encrinites, and shells, these fossils forming the curious ornamental markings on its polished surface. In certain localities some of the bands are dark and bituminous—forming, when polished, the "black marble" of the statuary; and others, when rubbed, or struck with the hammer, emit a highly fetid odour, well known as "stinksteins" and "swinestones." Occasionally the bitumen makes its appearance in the chinks and fissures in a free state, especially in the vicinity of trap dykes and irruptions; and thus we have springs of petroleum, and masses of elaterite, and slaggy mineral pitch, as in Derbyshire, Fifeshire, and Linlithgow. Besides being rent and dislocated like all other stratified rocks, it is further intersected by what are called *joints* or *divisional planes* (the "backs" and "cutters" of the quarryman)—these being fissures perpendicular to the lines of bedding, and causing the rock to break up in large tabular masses. These natural rents affording free passage to water, the mountain limestone is very often grooved and channeled—these channels, where the rock is thick, becoming caverns and grottoes of great extent and magnitude. It is

to this percolation of water charged with carbonic acid, that we owe not only these caverns and the beautiful *stalactites* and *stalagmites* which adorn their roofs and floors, but also the petrifying springs which abound in limestone districts. To the same cause, in like manner, we owe the production of *rotten-stone* from beds of siliceous limestone—the carbonated waters dissolving the limy portion and leaving the light, porous, siliceous residuum which forms the "rotten-stone" of commerce.

Palæontological Aspects.

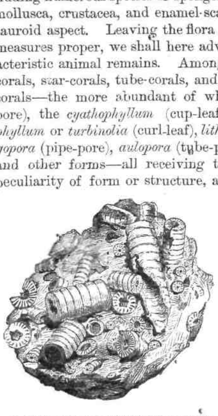
199. The palæontology of the Carboniferous limestone, as a group, is highly indicative of marine conditions; and in general the observer feels as little difficulty in accounting for its formation, as he does in accounting for the origin of an existing coral-reef. In the sandstones and shales that accompany the limestones, we



1, Syringopora; 2, Lithostrotion; 3, Aulopora; 4, Amplexus; 5, Clisiophyllum 6, Ptilopora; 7, Archimedopora.

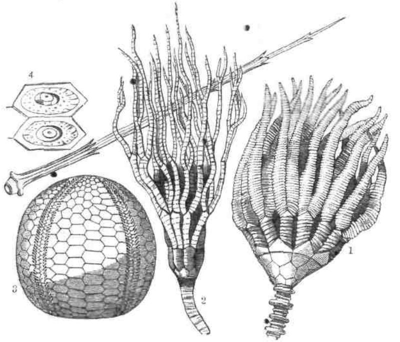
have the usual PLANTS of the true coal-measures; at least, so far as yet investigated, no real specific differences have been observed

In the calcareous beds there is an exuberant marine FAUNA, including numerous species of sponges, corals, corallines, encrinites, mollusca, crustacea, and enamel-scaled fishes, some of huge and sauroid aspect. Leaving the flora to be noticed under the Coal-measures proper, we shall here advert to a few of the more characteristic animal remains. Among the zoophytes we have cup-corals, star-corals, tube-corals, and branching and lamelliferous corals—the more abundant of which are the *astræopora* (star-pore), the *cyathophyllum* (cup-leaf), *cyathopsis* (cup-like), *clisiophyllum* or *turbinolia* (curl-leaf), *lithostrotion* (stone-spread), *syringopora* (pipe-pore), *aulopora* (tube-pore), *lithodendron* (stone-tree), and other forms—all receiving their designations from some peculiarity of form or structure, and most of them distinct and independent species. Of the echinoderms by far the most abundant are the *crinoidea*, or encrinites, whose jointed stems and branches often make up the entire mass of limestone; hence the frequent synonyme of "encrinal" or "encrinital limestone." As trilobites were especially characteristic of the silurian period, and bony-plated fishes of the old red sandstone, so may encrinites be regarded as peculiarly distinctive of the mountain limestone. They occur in endless varieties, but are all constructed on the same plan—viz., that of a cup-like body, furnished with numerous arms and branches, and attached to the sea-bottom by a jointed and flexible stalk. They derive their names chiefly from the shape of their cup-like bodies, or from that of the calcareous joints which compose the stalk. Thus we have the *cyathocrinus*, so called from the cup-like shape of its body; the *apiocrinus*, or pear-shaped; *rhodocrinus*, or rose-shaped; *poteriocrinus*, or goblet-shaped; *astrocrinus*, from the star-like disposition of its fingers; the *actinocrinus*, or spiny encrinite, and many other genera of these curious echinoderms. Besides the encrinites, or lily-shaped radiata, there are true star-fishes, like the *asterias* of our own seas, and echinoderms, like our sea-urchins,—their detached spines often covering the surfaces of limestone strata, and known as the *archæoci-*



Weathered fragment of Encrinital Limestone

daris (ancient cidaris), and *palæchinus* (ancient sea-urchin). Of the mollusca we have many of the compound net-like bryozoa,



1, Woodocrinus; 2, Cyathocrinus; 3, Palæchinus; 4, Plates and Spine of Archæocidaris.

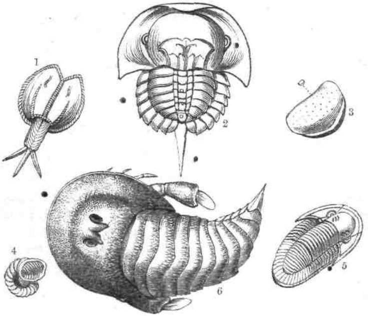
as *retepora* (net-pore), *polypora* (many-pore), *vincularia*, (chain-pore), *fenestella* (little window-pore), *ptilopora*, and other flustracea-like forms. Of the brachiopods, the *productus*, *terebratula*, *spirifera*, *pentamerus*, *rhynconella*, and *orthis* are found in almost every bed; so much so, that "productus limestone" is not unfrequently used as a synonyme. Among the lamellibranch bivalves, the most abundant are the *avicula*, *aviculopecten*, *inoceramus*, *posidonomya*, *modiola*, *myalina*, *nucula*, and *sanguinolites*. Of the pteropods we have the beautiful *conularia*, found in the limestones of Carluke, Campsie, Fife, and Bristol. Of the gasteropods, *euomphalus*, *bellerophon*, *loxonema*, *Murchisonia*, *natica*, and *pleurotomaria* are the prevailing forms; and of the cephalopods, *nautilus*, *goniatites*, and *orthoceras* are the predominating genera. In some localities, several of the preceding forms range throughout the whole system; and indeed it is not possible, in many instances, to separate the system into anything like well-marked groups. The annelids *serpula*, *serpulites*, and *microcon-*

chus (*spirorbis*), are found in all the groups; and so also of the

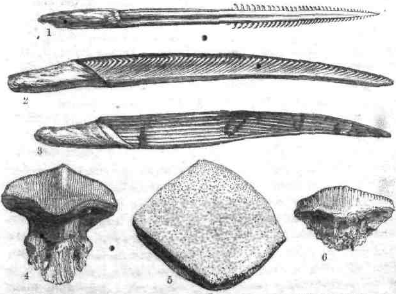
1, Terebratula; 2, Productus; 3, Spirifera; 4, Aviculopecten; 5, Bellerophon; 6, Loxonema
7, Murchisonia; 8, Pleurotomaria; 9, Euomphalus; 10, Conularia;
11, Goniatites; 12, Orthoceratite.

crustaceans *cypris*, *cypridina*, *dithyrocaris*, *eurypterus*, and *limulus*. The trilobites *Phillipsia* and *Griffithides* are confined more to the mountain limestone; and several beetle-like insects (*curculionides*) have been detected in the coal-fields of Coalbrookdale. Of the fishes which range throughout the system, but are certainly most abundant in the Limestone and Lower Measures, we may notice *megalichthys* (large fish), the *holoptychius Hibbertii*, the *rhizodus*, *palæoniscus*, *amblypterus*, *eurynotus*, and *platysomus*, which are often found pretty entire; the fin-spines *gyracanthus*,

ctenacanthus, ptycacanthus, pleuracanthus, &c., which occur of



1, Dithyrocaris ; 2, Limuloides (Bellinurus) ; 3, Cypris, magnified ; 4, Spirorbis (Annelid), magnified ; 5, Phillipsia (Trilobite) ; 6, Eurypterus (Isothea) Scouleri, from Linlithgowshire.



1, Pleuracanthus; 2, Gyracanthus ; 3, Ctenacanthus ; 4, Petalodus Hastingii ; 5, Psammodus porosus ; 6, Ctenoptychius serratus

large size, and present very curious forms and ornamentation; and the palatal teeth of cestracion-like fishes, which occur in great plenty, and have been erected into such provisional species as *psammodus*, *cochliodus*, *helodus*, *petalodus*, *ctenoptychius*, &c.—names derived from the forms, sculpturing, or external structure. As to the huge predatory fishes, to which many of these ichthyolites belonged, we know almost nothing, and, in absence of every other portion of their cartilaginous forms, must rest satisfied with temporary names and apparent affinities with living families. Another common fossil in the shales of the mountain limestone and coal-measures, as indeed in the shales of all the secondary formations, is the *coprolite* (*kopros*, dung, and *lithos*, a stone), or fossil excrement of fishes and saurians. In many instances coprolites contain scales, fragments of shells, &c., the remains of creatures on which these voracious animals preyed, and not unfrequently they exhibit the corrugations and convolutions of the intestines. In the coal-measures the coprolites are apparently those of fishes, and in many of the shales are so abundant as to constitute a notable proportion of the stratum.

III.—THE UPPER COAL-MEASURES.

200. This group, which completes the Carboniferous system, derives its name from the fact that it furnishes in Britain those valuable beds of coal which contribute so materially to our country's prosperity and power. Occurring immediately above the mountain limestone, or sometimes separated from it, as in the north of England, by thick beds of quartzose sandstone known as the *Millstone Grit*, it consists essentially of alternations of sandstones, grits, fire-clays, black bituminous shales, bands of ironstone, seams of coal, and occasional beds of impure limestone. One of the most notable features in its composition is the frequent recurrence of seams of coal and beds of bituminous shale—all bespeaking an enormous profusion of vegetable growth, and a long-continued epoch in the world's history, when conditions of soil, moisture, and climate conjoined to produce a flora since then unparalleled either in tropical forms or in abundance. It is this profusion of vegetable growth, now converted or mineralised into *coal*, which distinguishes the carboniferous from all other systems—the lakes, estuaries, and marine flats of the period being repeatedly choked with vegetable matter, partly drifted from a distance by river inundations, and partly

accumulated on the bed of its growth after the manner of peat-mosses, jungles, and submerged forests.—(For theories of formation, see Recapitulation.)

Lithological Composition.

201. The *Coal-measures*, as already stated, consist of alternations of sandstones, coals, shales, ironstones, clays, and impure limestones; the *Millstone Grit*, which is a local development, and not a persistent group, consisting mainly of thick-bedded quartz-ose sandstones, with subordinate layers of shale and coal. Among the multifarious beds of the coal group, there is no apparent order of succession, though gritty sandstones may be said to prevail at the base of the group, shales and coals in the middle, and sand-stones and marly shales in the upper portion—these gradually passing into the superior system of the new red sandstone. The sandstones occur in great variety, but are in general of a dull white or brown colour, and thick-bedded. Occasionally they are thin-bedded or flaggy, but in this case they are more or less mingled with carbonaceous, argillaceous, or calcareous matter. The coals also present numerous differences, according to the amount of earthy impurity that may have mingled with the original vegetable mass, the nature of the plants themselves, and the degree of decomposition these may have undergone before their final entombment and mineralisation. They are known to mineralogists as *anthracite*, a non-bituminous and semi-lustrous variety; *caking-coal*, a highly bituminiferous sort, like that of Newcastle, which cakes or undergoes a kind of fusion during combustion; *splint*, a less bituminous and slaty variety, which burns free and open, without caking; and *cannel*, a compact lustrous variety, which breaks with a conchoidal or shell-like fracture, and is extensively used in the manufacture of gas. In fact, among coals, as among all other mixed rocks, there is every degree of admixture, from a variety that may yield on combustion only some 1 or 2 per cent of ash, to another that may leave as much as 30 per cent of earthy residue, or even be so impure as to be altogether unfit for fuel. The names, therefore, by which the varieties of coal are known, must be viewed as popular and local, rather than as strictly scientific; though such terms as we have above indicated are certainly preferable to those often employed to designate the mere application of the varieties; as "steam-coal," "gas-coal," "furnace-coal," "household-coal," and the like. The shales are generally dark-coloured, and more or less bituminous

—many of them occurring as *alum-shales*, and some of them sufficiently *pyritous* to be used in the preparation of copperas. The limestones are often impure and earthy; and the ironstones occur in bands or in nodules—either as a clay-carbonate of iron, or in combination with bituminous or coaly matter, as the "black-bands" of Scotland. It is this natural admixture of coaly matter which confers on these black-bands their especial value, the raw stone being readily calcined—in fact, igniting and slagging itself—without the expensive admixture of coal, as is the case with the ordinary clay-ironstones and hæmatites. The clays—that is, the argillaceous beds which do not exhibit a laminated or shaly structure—occur also in every variety, from pure plastic clays to impure earthy mudstones. The *fire-clays* are those so called from their power of resisting heat without slagging or vitrifying, a property they possess from their freedom from lime and iron; and the *under-clays* are those which occur immediately underlying the seams of coal. At one time it was held by the advocates of the submergence theory (see Recapitulation), that every seam of coal has its under-clay, or soil-bed, on which the vegetation has grown and decayed; but this, like many other hasty generalisations, is far from being correct—some coal-seams resting hard on sandstone, and others immediately on calcareous beds, or even on other seams of coal.

202. In treating the lithology of the coal-measures, we must also remind the student how desirable it is to abide by scientific and intelligible terms, and to avoid the use of local and provincial names that cannot be understood beyond the limits of the district in which they are applied. Clay, shale, coal, ironstone, limestone, and sandstone, are well-known rocks, and any admixture of them can be readily described by a compound term expressive of the peculiar composition in question. Thus, a "ferruginous clay," a "calcareous shale," a "bitumino-calcareous shale," or an "argillo-calcareous sandstone," are designations which at once suggest the peculiar nature of the stratum; whereas the "faikes," and "blaize," and "sklut" of one coal-field—the "clunch," and "dogger," and "cat's-heads" of a second—or the "bratt," and "breeze," and "peldon" of a third—are terms which require explanation at every step, and, after all, are wanting in that precision which the advancement of science most imperatively demands. How worthless, therefore, are most of the *sections* and *journals of borings* occasionally published in official memoirs, and continually supplied by men professing to be mining engineers and coal-viewers! The truth is, for the purposes of scien-

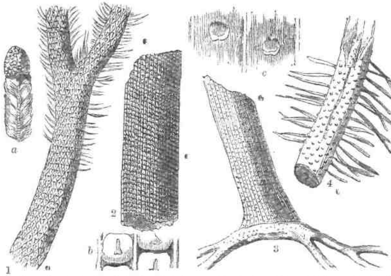
tific generalisation, nine-tenths of such sections are not only worthless, but, being calculated to mislead, are positively detrimental.

Palæontological Aspects.

203. The organic remains of the Coal-measures proper, though exhibiting many features in common with the groups already described, are still, as a whole, peculiarly well-defined. As an estuary or fresh-water deposit, many of the beds contain shells of *anthracosia*, *modiola*, &c. (the "mussel-bands," or "mussel-binds," of the miner), fishes, and other brackish-water exuviæ. A few encrinites and deep-sea brachiopods appear in certain exceptional beds of limestone, but otherwise marine types are subordinated, and estuary ones prevail. The fishes are chiefly of large size, and of sauroid character (*megalichthys*, *rhizodus*); in several fields—Germany, Belgium, Nova Scotia, Pennsylvania, and Britain—we have evidence of terrestrial life in the skeletons of certain batrachian-like reptiles (*archægosaurus* (ancient land-lizard), *dendrerpeton* (tree-lizard), *parabatrachus* (frog-like reptile), *baphetes*, *raniceps*, and *hylonomus*, as well as reptilian footprints known by the names of *batrachopus* and *sauropus*); and more recently land-shells (*pupa*), and remains of insects apparently allied to the cockroach, beetle, and grasshopper families (*curculionides*, *blattinæ*, and *gryllacris*), have been added to the carboniferous fauna. In these early reptiles—in the persistence of their dorsal chord, their gill-arches, their large median and lateral throat plates, and other piscine characters—Professor Owen traces a "linking and blending" of the two cold-blooded vertebrate groups; *archægosaurus* conducting, as it were, from the fish proper to those labyrinthodont reptiles that come boldly into force in the Permian and Triassic eras. The grand feature of the period, however, is the abundant and gigantic flora, comprising hundreds of forms which have now only distant representatives in tropical swamps and jungles. Araucarian-like pines, palms,* tree-ferns, gigantic reeds, equisetums, club-mosses, and other kindred forms, crowd every bed of shale,

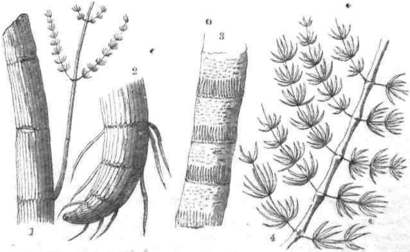
* It has been recently questioned, and apparently on good grounds, whether we have certain evidence of the existence of palms during the Carboniferous epoch? The three-cornered fruits (*trigonocarpum*), formerly supposed to be those of palms, are now regarded as those of coniferous plants, which, like the berry of the juniper, was enclosed in a fleshy envelope; while the broad flabelliform or fan-shaped leaves (*Noeggerathia*) are also considered coniferous and akin to the existing subtropical Salisburia. The so-called palm-stems have always been held as doubtful.

enter into many of the sandstones, and constitute thick seams of coal. Of the more characteristic of these forms we may



1, Lepidodendron Sternbergii; *a*, Lepidostrobus or cone of do.; 2, Favularia tessellata; *b*, Leaf scar of do.; 3, Sigillaria oculata, with stigmaria roots; *c*, Leaf scar of do.; 4, Stigmaria ficoides, showing rootlets and pith.

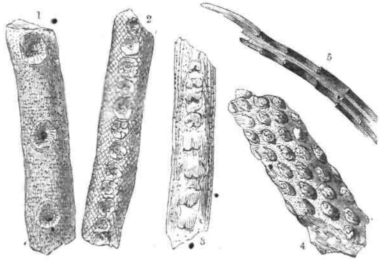
notice the *sigillaria* (*sigillum*, a seal), so called from the seal-like impressions on its fluted trunk; the *stigmaria* (*stigma*, a puncture), from the dotted or punctured appearance of its bark, and now ascertained to be the roots of sigillaria; the



1, Calamites nodosus; 2, Root of Calamite, with rootlets; 3, Hippurites gigantea; 4, Asterophyllites foliosa.

lepidodendron (*lepis*, a scale, and *dendron*, tree), from the scaly

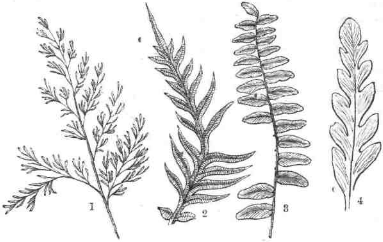
exterior of its bark ; *lepidostrobus* (*strobilus*, a cone), supposed to be the fruit-cone of the lepidodendron ; *lepidophyllum*, the leaf of the same ; *calamites* (*calamus*, a reed), from the reed-like jointings of its stem ; *hippurites*, from its resemblance to the existing mare's-tail of our ditches ; *asterophyllites* (*astron*, a star, and *phyllon*, a leaf), from the star-like whorls of its leaves ; *pinites*, from their pine-like affinities ; *antholites* (*anthos*, a flower), fossil flowers, thus indicating the existence of phanerogamous or flowering plants ; *carpolithes* (*carpon*, fruit), fossil fruits ; *trigonocarpon* (three-cornered fruit) ; *bothrodendron*, pitted stem, from the large circular cone-scars arranged on either side the trunk ; *ulodendron*, *sternbergia*, *knorria*, *favularia*, *halonia*, and many other



1. Bothrodendron punctatum ; 2, Ulodendron minus, 3, Megaphyton approximatum ; 4, Caulopteris Phillipsia ; 5, Knorria taxina.

stems, leaves, and fruits. In fact, the majority of these vegetable organisms are named from some peculiarity of form, the ablest botanists being yet unable to assign them a place among existing genera. Nor is this defect to be altogether wondered at, considering the difficulties attending the classification of living forms of vegetation, and the doubts that must necessarily hang over such obscure and imperfect fragments as present themselves to the palæophytologist. Still, the state of Fossil Botany is by no means creditable to the science of the age, and lags far behind its sister department of Fossil Zoology. Of the fern-like impressions—so abundant in the shales, and which must meet the eye of the student in almost every fragment he splits—the following may be taken as typical forms : *sphenopteris*, or wedge-fern (*sphen*, a wedge, and *pteris*, a fern), from the wedge shape of its leaves ;

pecopteris, or comb-fern (*pekos*, a comb); *neuropteris*, or nerve-fern; *cyclopteris* (*cyclos*, a circle), or round fern; *odontopteris*, or



1, Sphenopteris affinis; 2, Pecopteris lonchitica (pinnule); 3, Neuropteris gigantea (pinnule); 4, Odontopteris obtusa (pinnule).

tooth-fern; *otopteris*, or ear-fern; and so on with many similar forms.

204. Whatever the botanical families to which these extinct vegetables belong, they now for the most part constitute solid seams of coal—coal being a mass of compressed, altered, and mineralised vegetation, just as sandstone is consolidated sand, or shale consolidated mud. By what chemical processes this change has been brought about, we need not minutely inquire; but we see in peat and in lignite the progressive steps to such a mineralisation; and when thin slices of coal are subjected to the microscope (as was originally done by Witham and Nicol, and now so admirably by Mr A. Bryson of Edinburgh), its organic structure is occasionally as distinctly displayed as the cells and fibres in a piece of timber. Of the amount of vegetation required to form not only one seam, but forty or fifty seams, which often succeed each other in coal-fields, we can form no adequate conception, any more than we can calculate the time required for their growth and consolidation. This only we know, as will be more fully adverted to in the Recapitulation, that conditions of soil and moisture and climate must have been exceedingly favourable; that over a large portion of the globe such conditions then prevailed; and that partly by the drift of gigantic rivers, and partly by the successive submergences of forests, marinejungles, and peat-swamps, the vegetable matter was accumulated which now constitutes our valuable seams of coal.

Geographical and Physical Aspects.

205. The geographical area occupied by the Carboniferous system, in one or other of its groups, is pretty extensive, though our workable coal-fields are for the most part found in limited and detached "basins." The system is very typically developed in various parts of the British Islands, and to this circumstance is mainly owing our greatness as a nation—the formation being rich in coal, iron, and lime, three mineral products most essential to civilised existence. Available coal-fields occur in the central counties of Scotland, in the northern and middle districts of England, in Wales, and in Ireland; they occur also in some districts of Spain, in central France, Germany, and in middle Europe; in Hindostan and Australia; on the coasts of Chili and Peru; in the Isthmus of Panama; in Melville Island and Nova Scotia; and covering an aggregate area of more than 600,000 square miles in the United States of America. It must be observed that we here speak of the old or *Palæozoic coal-fields*, and not of available coal-fields which belong to the oolite and other later formations. It is a common but mistaken notion, that all the bituminous coals belong to one great period or formation; whereas coal is a product of all periods, and thus many fields now assigned to the Carboniferous era will yet be found to be exclusively of Oolitic and even of later epochs. The coals of Southern India, of Borneo, Labuan, Zebu in the Philippine Islands, &c., are now ascertained to be of Oolitic age; to which epoch also it is suspected that most of those found in China and Japan belong; as well as that of Virginia in America, and other localities. The coals of Vancouver's Island and the Saskatchewan prairies are said to be of cretaceous age; while those of New Zealand and the islands of the Pacific appear to be tertiary like the lignites of Germany, though local conditions of deposit may have rendered them more bituminous than ordinary lignite. In fact, there are few subjects so much requiring a competent revision as the reputed "coal-fields" of distant countries, which evidently belong to different ages—ranging, as we have already said, from Palæozoic to Cainozoic eras.

206. During the whole of the carboniferous epoch we have ample evidence of igneous activity. In the lower coal-measures we have frequent interstratifications of trap-tuff and ash, and these become more abundant in connection with the mountain limestone. Subsequent to the deposition of the system, it seems

to have been shattered and broken up by those forces which elevated the trap-hills of the mountain limestone, and gave birth to the numerous basaltic crags and conical heights of our coal-fields. The traps are chiefly augitic, and consist of basalts, greenstones, clinkstones, claystones, trap-breccias, trap-tuffs, and earthy amygdaloids. The upheavals and convulsions of the period have greatly dislocated the strata, and most of our coal-fields exhibit trap-dykes, faults, and fissures in great complexity and abundance. To this intensity of igneous action must also be attributed the fact that many of the coal-traps contain a notable percentage of bituminous matter, yielding to analysis from .5 to 3 and 5 per cent. Not only do many of them retain portions of the bitumen caught up during their original fusion, as at Blebo in Fife, but *in their chinks and fissures*, as well as *in the strata through* which they pass, do we find nests of pitch and asphalt, while petroleum springs are not unfrequent in the more disturbed districts of our coal-fields (Derby, Gloucester, and Mid-Lothian). If we except the hills of the mountain limestone, some of the basaltic crags and cones, and now and then a glen of erosion cut through the softer strata of the system, the scenery of coal districts is on the whole rather tame and unpicturesque. The soil, too, in general derived from the shales and clays beneath, is often cold and retentive, and requires all the skill and appliances of modern agriculture to render it moderately fertile. These drawbacks, however, are more than compensated for by the value of the mineral treasures beneath.

Industrial Products.

207. The industrial importance of the carboniferous system can only be adequately appreciated in a country like Britain, which owes mainly to it the proud mechanical and manufacturing position she now enjoys. *Building-stone* of the finest quality is obtained from the sandstones of the lower groups (Edinburgh, Fife, Glasgow, and Newcastle); *limestones* for mortar, hydraulic cement, iron-smelting, agricultural and other purposes, are quarried from the middle group; and *marbles* of not indifferent beauty (Derbyshire, Kilkenny, &c.) are derived from the same set of strata—the joints and stalks of encrinites, the star-like pores of the corals, and sections of shells, shining out from the darker matrix in which they are imbedded. *Ironstone*, both blackband and clay-carbonate, is mined in almost every coal-field, and constitutes a large proportion of the supply in Great

Britain ; *fire-clay* for bricks, tiles, drainage-pipes, retorts, and other uses, is extensively raised from many coal-workings ; *ochre* (hydrated oxide of iron) is obtained in several localities ; *alum* is largely prepared from some of the shales, as near Glasgow and in Germany ; and *copperas* or green sulphate of iron is manufactured from similar pyritous clay-shales. Our sole supply of *coal* in this country (amounting to nearly 72,000,000 tons annually for domestic, manufacturing, and export purposes) is procured from this system, which, if we except a few oolitic and cretaceous coal-fields and tertiary lignites, is also the main repository of this valuable mineral in other regions of the globe. *Petroleum* and *asphalt* are also products of the system, though substances of this nature (naphtha, paraffine, coal-tar, &c.) are obtained chiefly by distillation of one or other of the varieties of coal. The mountain limestone is also in this country the chief repository of the ores of *lead*, *zinc*, and *antimony*, and much of this lead-ore contains an available percentage of *silver*. On the whole, the carboniferous system is decidedly the most valuable and most important to man ; and when we name the principal coal-fields of Britain, we point at the same instant to the busiest centres of our manufacturing and mechanical industry.

NOTE, RECAPITULATORY AND EXPLANATORY.

208. The strata we have now described constitute a well-marked and peculiar system, lying between the old red sandstone beneath, and the new red sandstone above. Their most striking peculiarity is the profusion of fossil vegetation, which marks less or more almost every stratum, and which in numerous instances forms thick seams of solid coal. It is to this exuberance of vegetation that the system owes its name—*carbon* being the main solid element of plants and coal. Although this coaly or carbonaceous aspect prevails throughout the whole, it has been found convenient to arrange the system into three groups—the Lower Coal-measures or Carboniferous Slates, the Mountain or Carboniferous Limestone, and the Upper or True Coal-measures ; or more minutely, as is generally done by British geologists, into—

1. Upper Coal-measures.
2. Millstone Grit.
3. Mountain Limestone ; and,
4. Lower Coal-measures.

Other subdivisions have been attempted according to the local peculiarities of different coal-fields; but it is enough for the purposes of the general student to know that all these minor arrangements can be readily co-ordinated with one or other of the above four series. Thus Sir R. Griffiths, in his *Geological Map of Ireland*, gives the annexed subdivisions:—

a. Coal-measures, upper and lower, .	1000 to 2200 feet.
b. Millstone Grit, ...	350 ,, 1800 ,,
c. Mountain Limestone, upper, middle, and lower, ...	1200 ,, 6400 ,,
d. Carboniferous Slate, ...	700 ,, 1200 ,,
e. Yellow Sandstones (of Mayo, &c.), with shales and limestones, . . .	400 ,, 2000 ,,

Now, here there is this little difficulty in co-ordinating, as we have first the usual members of the system, *a*, *b*, *c*, and *d*, and a subjacent series, which lies fairly open to the question whether it is Upper Devonian or Carboniferous. In the mean time, the *majority of evidence inclines to the former opinion; and that the* so-called "yellow-beds" are the true equivalents of the Dura Den series, which is rich in *holoptychius*, *pterichthys*, and other Devonian fossils. Again, the carboniferous strata of the south of England (on the Avon, near Bristol) are given in the *Geological Survey's Memoirs* as consisting of—

a. Millstone Grit—here mostly a hard reddish grit-stone, the grains often almost confluent, as in what are called quartzites and quartz-rocks, .	950 feet.
b. Alternations of Limestone, red or grey, compact or granular, with shales, red, dark, or grey, and sandstones. Most of the strata fossiliferous, and Producta gigantea abundant near the base, .	400 ,,
c. Scar Limestones—grey, reddish, mottled, brown, and black; compact, shelly, crinoidal, and oolitic, in beds varying in thickness, and partially divided by shales, ...	1440 ,,
d. Lower Series, enclosing many alternations of limestones and shales, the former often black, brown, yellowish, sometimes impure, and in one part charged with fish-remains and cyprides in abundance, ...	500 ,,

⁎ The upper part of the Old Red shows yellow and grey sandstones and marls.

In this case there can be no difficulty in at once assigning *b* and *c* to the great series of the Mountain Limestone; while *d* is evidently the equivalent of the "Lower Coal-measures" of Scotland, with a few of its beds graduating, it may be, into the yellow sandstones of the underlying Devonian. In Fifeshire, on the other hand, we have—

a. True Coal-measures—consisting of numerous alternations of coal, shales, sandstones, ironstones, and occasional beds of impure limestone, .	2500 feet.
b. Several strata of crinoidal and productus limestone, with intervening beds of shale, sandstones, and thin seams of coal, ...	200 ,,
c. A vast thickness of whitish fine-grained sandstones, bituminous shales, a few thin seams of coal, mussel-bands or shell-limestone, and fresh-water limestones abounding in cyprides, . .	2000 ,,

In this instance there is no development of millstone grit—the whole system resolving itself, as it does in many other regions, into Upper Coal, Mountain Limestone, and Lower Coal. In Nova Scotia, again, we have in the lower series a vast development of gypseous beds, which look somewhat puzzling at first sight to an English geologist, but which, when taken in connection with the associated shales and coals and fossils, admit of easy co-ordination on the large scale with the main subdivisions established by British geology. How far these subdivisions may indicate separate life periods, or only portions of one great epoch, has yet to be determined by a more minute and rigorous comparison both of vegetable and animal species—a task that has hitherto been neglected for the lighter labour of popular description and attractive generalisation.

209. Looking, in the mean time, at the whole succession and alternations of the strata—the sandstones, clays, shales, limestones, ironstones, and coal—and noting their peculiar fossils—the estuary character of the shells and fishes of the lower and upper groups, and the marine character of the corals, encrinites, shells, and fishes of the middle group, with an excess of terrestrial vegetation throughout—we are reminded of conditions never before or since exhibited on our globe. The frequent alternations of strata, and the great extent of our coal-fields, indicate the existence of vast estuaries and inland seas, of gigantic rivers and periodical inundations; the numerous coal-seams and bituminous shales clearly bespeak conditions of soil, moisture, and warmth favourable to an exuberant vegetation, and point partly to vegetable drift, and partly to submerged forests, to peat-swamps and estuarine jungles; the mountain limestone, with its marine remains, reminds us of low tropical islands fringed with coral-reefs, and lagoons thronged with shell-fish and fishes; the existence of reptiles and insects tells us of air, and sunlight, and river-banks; the vast geographical extent of the system bears evidence of a more equable climate over a large portion of the earth's surface; while the interstratified trap-tuffs, the basaltic outbursts, and the numerous faults and fissures, testify to a period

of intense igneous activity—to repeated upheavals of sea-bottom and submergences of dry land. All this is so clearly indicated to the investigator of the carboniferous system, that he feels as convinced of their occurrence as if he had stood on the river-bank of the period, and seen the muddy current roll down its burden of vegetable drift; threaded the channels of the estuary, gloomy with the gigantic growth of swamp and jungle; or sailed over the shallow waters of its archipelago, studded with reef-fringed volcanic islands, and dipped his oar into the forests of encrinites that waved below.

210. The natural conditions under which the system was formed are not more wonderful, however, than the economical importance of its products. Building-stone, limestone, marble, fire-clay, alum, copperas, lead, zinc, silver, and, above all, iron and coal, are its principal treasures—conferring new wealth and comfort on the country that possesses them, and giving a fresh and permanent impetus to its industry and civilisation. Indeed, it is scarcely advancing too much, when we assert that coal and iron are indispensable to the development and progress of modern civilisation; and that reference to the "coal-fields" of a geological map is almost tantamount to an expression of population, industry, and mechanical achievement.

Formation of Coal.

211. With regard to the formation of coal, geologists are by no means fully agreed, nor do the facts of the science yet warrant a dogmatic decision. Some twenty or thirty years ago, the subject was a favourite one with writers on geology, the most positive views being generally put forward by those who had the least practical acquaintance with the subject. On examining sandstone and shale, it is easy to perceive, from their texture and composition, that they must at one time have been respectively loose sand and mud, borne down by, and deposited from, water; but the case is somewhat different with beds of coal. This mineral being chiefly composed of carbon, hydrogen, and oxygen—the same elements (though differing in proportion) which enter into the composition of plants—and revealing in its mass evidence of vegetable structure, no doubt is entertained of its organic origin. But whether the plants of which it is composed were drifted down by rivers, and deposited along with layers of mud and sand in estuaries, or whether dense forests and peat-mosses were submerged, and then overlaid by deposits of sand and mud, are the two main ques-

tions at issue. According to the latter hypothesis, the vegetable matter must have grown and accumulated in dense jungles and peat-mosses for many years; then the land must have sunk and become the basin of a lake or estuary, into which rivers carried mud and sand; these, covering the vegetable matter, gradually consolidated into shales and sandstones, while the vegetable matter itself underwent the process of bituminisation and mineralisation, and was converted into coal. This being done, or while in process of being done, it is supposed that the area of deposit was again elevated, or at least so far silted up and rendered so shallow as to become once more the scene of luxuriant vegetation; again submerged in the process of gradual subsidence, and overlaid by new deposits of sandstone and shale; once more shoaled and covered with plants, and then submerged; and this alternating process of submergence and shoaling is presumed to have taken place as often as there are beds of coal in any particular coal-field. The other hypothesis is, that while partial elevations and submersions of the land might have taken place, as at the present day, and jungles, pine-swamps, and peat-mosses being thereby thrown beneath the waters, the great masses of the coal-measures were deposited as *drift* and *silt* in lakes and estuaries; that the vegetable matter of which coal is composed was carried into these estuaries by rivers and inundations; and that various rivers might discharge themselves into one estuary—some chiefly carrying down sand, while others transported plants, mud, and heterogeneous debris. This hypothesis also supposes that the transporting rivers were subject (like the Nile, Ganges, &c.) to periodical inundations, and that during the intervals of overflow the deltas were choked with a rank growth of vegetation, which, in conjunction with the vegetable drift from inland, went to the formation of beds of coal.

212. Such are the two prevalent hypotheses that have been advanced to account for the origin of coal, and which are sometimes known as the "terrestrial" or "peat-moss" and "drift" theories. Like most other debated points in science, the disputants have carried their respective notions a little too far, and relied too exclusively on what may have been their own local and limited observations. The fact is, there is truth in both, and both must be called into play to account for well-known appearances in almost every coal-field. In inventing hypotheses, our first appeal should be to existing nature; and there we find both peat-moss, and forest and jungle, the drift of rivers, and the silt of lakes and estuaries. Submerged peat-mosses, forests, and estuarine jungle-growths are just as likely to occur in the course of nature's operations, as the

drifted rafts of rivers, or the periodical inundations of tropical deltas; and it is only by calling in the aid of both hypotheses that we can possibly arrive at any satisfactory conclusion. Relying on the former theory alone, a subsidence and shoaling must have taken place for every seam of coal; and as in some fields as many as sixty seams occur, varying in thickness from a few inches to 4, 6, 8, 10, 12, and 20 feet, it is difficult to conceive the repeated re-establishment and growth of a flora under conditions so varying and unstable as these oscillations would necessarily imply. It is also objected to this theory, that some thick beds of coal are subdivided by layers or "partings" of sandstone or shale—a fact that would imply several elevations and submergences during the formation of a single coal-bed; whereas, by the latter hypothesis, those layers of sandstone, &c., present no difficulty, as the river, while it bore down vegetable drift, would carry, at the same time, sand and other debris. Further, shells, fishes, fish-spines, and coprolites are frequently imbedded in coal; and it is difficult to conceive how these could have got there, unless in the ordinary way of deposit and sediment. Forests of coniferæ, palms, and tree-ferns could not have been so frequently and tranquilly submerged without the trunks being more abundantly found in an upright and growing position—a position only occurring in certain strata, and over comparatively limited areas. Again, had coal resulted solely from submerged pine-swamps, jungle-growths, and peat-mosses, there is no mode of accounting for the occurrence of shells, fishes, and layers of sandstone in its mass. By calling in the aid of both hypotheses, all these difficulties disappear; and we see in some thick, continuous, and pure beds of coal the remains of submerged peat-mosses or pine-swamps; in others, the matted masses of drift vegetation, enclosing shells and fish-bones; in some, the upright trunks and accumulated foliage of gigantic forests, with their "underclays" or ancient soils on which they flourished; while beds of impure coal or bituminous shale bespeak the preponderance of muddy silt among the drifted vegetation that slowly decayed and dropped to the bottom of the estuary of deposit. In fine, no one can look at the frequent alternations of coal, ironstone, limestone, sandstone, shell-limestone, fire-clay, shale so argillaceous as to be little else than consolidated mud, and shale so highly bituminous as to be nearly as inflammable as coal, but must see at once the varying agencies of rivers, lakes, and estuaries—of inundations and submergences—of elevations *into dry forest and jungle growth, and anon, and for ages, depression*, in proportion to the thickness of the coal strata, beneath the waters of deposit. We have thus a variety of agencies at work,

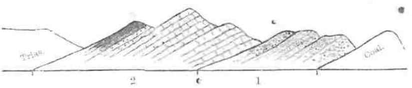
but agencies which still find their analogues in existing nature; and when the student is reminded of the rafts of the Mississippi, the pine-barrens and cedar-swamps of America, the peat-mosses of Europe, the mangrove jungles of the Niger, the low shifting mudbanks and islands of the Ganges, the far-stretching sandy shores of Holland, backed by their extensive peat-marshes, and the numerous coral-reefs and lagoons of the South Pacific, he can have little difficulty in forming some conception of the shallow seas, estuaries, and submerged areas in which the sandstones, shales, shell-limestones, and coal-beds of the carboniferous system were deposited.

213. There is still this difficulty, however, and one which has given rise to a vast amount of ingenious speculation and improbable hypothesis—viz., the apparent sameness of external conditions over such extensive areas of the earth as are occupied by our known coal-fields. The same gigantic coniferous and filicoid plants are found alike in the coal-fields of Britain, America, Melville Island, and Australia—regions at once tropical, temperate, and arctic. To account for this luxuriance and homogeneity of vegetable growth, the greater effect of the earth's central heat, a larger percentage of carbonic acid in the atmosphere, change in the earth's axis of rotation so as to bring the coal-areas within the influence of the tropics, greater eccentricity of the earth's orbit, the planetary system moving through warmer regions of space, and the like, have been variously suggested. Before having recourse, however, to such abnormal conditions, science should first exhaust the causes and agencies of existing nature, and know something more of the real character of the plants whose mass has contributed to the formation of coal. Gigantic coniferæ, tree-ferns, club-mosses, and equisetums, do not necessarily imply tropical conditions of temperature; the climate under which the lepidodendron, sigillaria, and other plants of unknown affinities flourished, seems to have been more humid and equable than tropical; the peat-mosses of Europe accumulate under temperate or even coldly-temperate conditions; and physical geography has not yet told, with anything like certainty, the climatic results attending different distributions of sea and land, with lower altitudes of islands and continents, and different oceanic currents concentrating thereon their incessant supplies of genial heat and moisture. Besides all this, we have coal-beds in other formations—the oolite, wealden, chalk, and tertiary; and if we are to go in search of abnormal conditions for the production of the one, we must admit the existence of similar causes for the production of the other—an admission, as we shall afterwards see,

that would lead to irreconcilable absurdities. The fact is, coal is a necessary product of every period, and is merely the mineralised result of vegetable accumulation—pointing rather to immensity of time and peculiarity of external conditions than to rapidity of growth as the causes of that accumulation. Again, we have no proof that the coal-fields of Europe, America, and Australia were strictly contemporaneous. Though containing the same generic fossils, vast periods may have elapsed between their respective formations, just as we find the same shells now living in the Greenland seas that ages ago were entombed in the "glacial" silts of the Clyde and other estuaries. Further, as in the case of the great tertiary elephants and rhinoceroses of northern Europe, whose representative species are now found only in the tropics, the plants of the coal-measures, though presenting a sub-tropical facies of growth, may, after all, have been inhabitants of temperate and warm-temperate climates—rooted in the rich organic muds of swamps and inundated estuaries, and stimulated by the moist and genial atmosphere of warmer oceanic currents. Till all this is better known—and geologists are gradually accumulating facts in this direction—it were more philosophical merely to describe and chronicle the phenomena, than to outrage the laws of nature by appeals to the abnormal and marvellous.

214. *The limits of an elementary treatise necessarily restrict* our remarks to the more prominent features of the science; but enough, we presume, has been indicated to convince the student that, whether in its practical or theoretical bearings, the carboniferous system is one of the most interesting and important. To those who wish for further details, we may mention the instructive monographs which have appeared from time to time in the *Reports of the British Association*, in the *Memoirs of the Geological Survey*, and in the *Records of the School of Mines;* various able papers on local coal-fields in the *Transactions of the Geological Society*, in the *American Journal of Science*, the *Transactions of the Royal Society of Edinburgh*, and of the *Natural History Society of Newcastle*, as well as several prize essays of merit in the *Transactions of the Highland and Agricultural Society of Scotland*. For the flora of the system, the works of Lindley and Hutton, Dr Hooker in *Memoirs of Geological Survey*, A. Brongniart, Göppert, Sternberg, Endlicher, Dunker and V. Meyer, may be consulted with advantage; while Sowerby's *Mineral Conchology*, Parkinson's *Organic Remains*, the *Decades of the Geological Survey*, the monographs of the *Palæontographical Society*, Agassiz's *Fossil Fishes*, and Davidson's *Monograph of the Scottish Carboniferous Brachiopoda*, will furnish nearly all that is

yet known of the fauna of the period. Much valuable information will also be found in Williams's *Mineral Kingdom* (a work of some date); in Dawson's *Acadian Geology;* in Taylor's *History and Statistics of Coal;* in Professor Johnston's *Economy of a Coal-Field;* in Fordyce's recent work on the *Coal, Iron, Coke, and Coal-Fields of Britain;* in Hull's *Coal-Fields of Great Britain;* and in the more popular pages of the little work, *Our Coal-Fields and our Coal-Pits.*



XIII.

THE PERMIAN SYSTEM:

EMBRACING—1, THE LOWER NEW RED SANDSTONE; AND, 2, THE MAGNESIAN LIMESTONE.

215. IMMEDIATELY above the coal-measures—in some instances lying unconformably, and in others insensibly graduating from them—occurs a set of red sandstones and pebbly conglomerates, yellowish magnesian limestones, and variegated shales and marls, enclosing irregular masses of rock-salt and gypsum. To this series of strata, as more especially developed in England, the earlier geologists applied the term *New Red Sandstone*, in contradistinction to the old red sandstone system, which we have already described as lying beneath the carboniferous formation. Though the sandstones are not all red, nor the limestones the only magnesian limestones in the crust of the earth, still reddish hues prevail throughout the sandstones and shales as developed in the British Islands, and the calcareous beds are certainly more eminently magnesian than any others with which we are acquainted; hence the necessity of retaining, less or more, the terms "new red sandstone" and "magnesian limestone" in the nomenclature of geology. At one time the terms *Poikilitic* (*poikilos*, variegated) and *Saliferous* (salt-yielding) were applied to the system; but the fact that variegated marls abound in the old red, and that salt is found in several other systems, has rendered these designations all but obsolete. More recently it has been proposed to divide these new red sandstones, magnesian limestones, and saliferous marls into two distinct systems, the *Per-*

mian and the *Triassic*—the former embracing the lower members, which are largely and typically developed in the government of Perm, in Russia; and the latter comprising the upper members, known as the "Trias," or triple group, in Germany. The reasons for this new arrangement are, that the fossils of the magnesian limestone and lower red sandstones seem more closely allied to those of the coal-measures beneath, than to those of the variegated sandstones and saliferous marls above—in other words, present a *palæozoic* aspect; while those of the upper sandstones and marls are decidedly *mesozoic*. Such new divisions and arrangements must ever be expected in a progressive science like Geology, and more especially since, by associated organic forms, as indicative of great *life-periods*, and not by mere mineral aggregations, the history of the globe is to be measured and arranged.*

216. To render the new arrangements more intelligible, let us suppose, with Professor Phillips, all the red sandstones, marls, and magnesian limestones, hitherto known in England as "The New Red Sandstone," to be present in one section. We should then have, reposing unconformably on the coal-strata, the following tabulation, beginning from above :—

MESOZOIC, or TRIASSIC.	4. Series of coloured marls.	Purple-coloured marls below the lias. Alternations of red and bluish-white marls, with layers and nodules of gypsum. Thin layers of argillo-calcareous stone. Red and bluish marls, with gypsum and beds of rock-salt.
	3. Variegated red and white sandstone.	Red and white sandstone, mostly fine-grained, and often impregnated with salt. Red conglomerate, full of pebbles of older rocks.
PALÆOZOIC, or PERMIAN.	2. Magnesian limestone.	Red and white marls. Thin-bedded compact limestone, with very little magnesia, and few organic remains. Red and white marls and gypsum. White, yellow, or reddish magnesian limestone in thick beds, crystallised, compact, or earthy, often full of sparry cavities, and containing marine organic remains. Marl slate in thin layers, occasionally enclosing fishes.
	1. Yellow or purple sand, and sandstone, and marl.	An extremely variable series of sandstones, sands and clays of various colours, irregular thickness, and much local diversity of character. Plants like those of the coal-measures.

From the preceding tabulation, the student will perceive at a glance the limits of the Permian and Triassic systems (as developed in England), which we shall now proceed to describe as distinct

and independent life-periods. And, first, of the PERMIAN, a designation proposed by Sir Roderick Murchison, in 1841 (to harmonise with his Silurian, Devonian, &c.), from the Russian government of Perm, where these strata are more extensively developed than elsewhere, occupying an area twice the size of France, and containing an abundant and varied suite of organic remains.

Lithological Composition.

217. The Permian system, as developed in England, Germany, and Russia, consists essentially of reddish and occasionally whitish quartzose sandstones; of reddish and variegated shales (mottled, purple, yellow, and green); of yellowish limestones, containing a notable percentage of magnesia; and of calcareous or marly flagstones, often largely impregnated with copper-pyrites. The sandstones are generally thick-bedded, sometimes gritty, occasionally conglomerate, or rather more *pebbly* than conglomerate; the rolled pebbles being scattered throughout the sandstone strata, and seldom in vast bouldery masses, as in the old red conglomerates. The shales are usually called "marls," but this less from their containing any notable quantity of lime, than from their occurring in a mottled, friable, and non-laminated state. The limestones vary from an almost pure carbonate of lime to an admixture containing upwards of forty per cent of carbonate of magnesia—hence called "magnesian limestones." Their structure is often peculiar, occurring in thick beds, with subordinate concretionary masses, and layers of a powdery consistence, and not unfrequently in a peculiar brecciated or pseudo-brecciated arrangement, as if the mass on consolidation had been broken up internally and again reconsolidated. The concretions are often of curious shapes—*honeycombed*, *mammillary* (or pap-like), and *botryoidal* (or in clusters like a bunch of grapes)—structures which are very typically exhibited in the limestones of Sunderland and Durham. When the magnesian limestone assumes a granular and crystalline texture, it is known by the mineralogical name of *dolomite*, after the French geologist, M. Dolomieu. The slaty or flaggy beds are known in England as "marl-slates;" and in Germany, where they are largely impregnated with copper-pyrites, as "keuper-marls," and "kupfer-schiefer" (copper-slate), names now quite familiar to British geologists. Occasionally, as in the neighbourhood of Bristol, where the Permian beds rest unconformably on those of the coal-measures, we have a "dolomitic conglomerate;" that is, a conglomerate or breccia made up

of the fragments of the older rocks, and cemented together by a basis of reddish or yellow magnesian limestone. "This conglomerate or breccia, for the imbedded fragments are sometimes angular, occurs in patches" (we quote Sir Charles Lyell) "over the whole of the downs near Bristol, filling up the hollows and irregularities in the mountain limestone, and being principally composed at every spot of the debris of those rocks on which it immediately rests. At one point we find pieces of coal-shale, in another of mountain limestone, recognisable by its peculiar shells and zoophytes. Fractured bones, also, and teeth of saurians, are dispersed through some parts of the breccia."

218. With respect to the order of succession among the strata, the Permian, like every other system, presents local differences and irregularities. In the vast and undisturbed region of Central Russia it consists (according to Sir R. Murchison) of three main members, which may be arranged in descending order, thus :—

3. Conglomerate and sandstone, with plants and fossil reptiles.
2. Red sands, with copper ore and many plants.
1. Sandstones and grits; limestones in various courses, with characteristic fossils, associated with marls and gypsum, the marls occasionally containing plants, and also seams of impure coal.

In the north of England (more especially in Durham and Yorkshire), it is composed chiefly of red sandstone and grits, of magnesian limestones and gypseous marls, and of laminated calcareous flagstones. This succession is usually tabulated as follows :—

MAGNESIAN LIMESTONE.	LAMINATED LIMESTONE, with layers of coloured marls, as at Knottingley, Doncaster, &c. GYPSEOUS MARLS—Red, bluish, and mottled. MAGNESIAN LIMESTONE—Yellow and white; of various texture and structure; some parts, as at Tynemouth, brecciated, or made up of fragmentary masses. MARL SLATES—Laminated, impure calcareous flagstones of soft argillaceous or sandy nature.
RED SANDSTONE.	RED SANDSTONE, with red and purple marls, and a few micaceous beds. The grits are sometimes white or yellow, and pebbly. When conformable, this sandstone occasionally passes into the coal-measures on which it rests.

In France, Germany, North America, and other tracts where the system has been investigated, some of these members are wanting, while others are more fully and typically developed. It has been attempted by Professor King to co-ordinate, as in the subjoined synopsis, the English and German strata, taking the north of England and Thuringia as the points of comparison;

but the student should ever remember that, curious as such resemblances frequently are, it is by general types, and not by any conventional arrangement of strata, that the geologist must be guided in his deductions :—

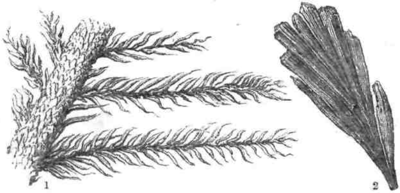
In England.	*In Germany.*
Laminated limestones.	Stinkstein.
Brecciated limestone.	Rauchwacké.
Fossiliferous limestone.	Dolomit ; upper zechstein.
Compact limestone.	Zechstein (mine-stone).
Marl slate.	Mergel-schiefer and kupfer-schiefer.
Red sandstones and grits.	Rothe-tode-liegende.

219. Taken as a whole, the student must perceive that a great difference exists between the red sandstones, magnesian limestones, and mottled marls of the Permian strata, and the gritty sandstones, bituminous shales, and coal-seams of the carboniferous system. It is true that in some localities the lower red sandstones show traces of calamites, ferns, and other coal plants ; but such graduations between systems are by no means uncommon, and the transition beds may be classed with either system without much impropriety. As we ascend to the Trias the difference becomes still more perceptible ; in fact, while several organic forms are common to the Permian and coal-measures, not a few of the Trias are identical with those of the superincumbent Lias. It was this passage or transition from one great system of life to another, that induced the earlier geologists to classify the new red sandstone, the carboniferous formation, and the old red sandstone, as Lower or Older Secondaries, and the lias, oolite, and chalk as the Upper or Younger Secondaries. Though now seldom used, these distinctions were not without their significance, and gradually led the way to the more precise arrangement of the stratified systems into Palæozoic, Mesozoic, and Cainozoic. Abiding by these life-periods, the Permian, as containing fossils less or more allied to carboniferous types, takes rank as *Palæozoic ;* while the Triassic, enclosing fossils less or more allied to oolite types, takes rank with *Mesozoic* systems, as already indicated in the tabular summary, page 99, to which the student is here requested to refer.

Palæontological Characteristics.

220. The organic remains of the Permian system, as far as discovered, do not appear to be very abundant, and with this paucity of fossils it would be unsafe to d gmatise too confidently as to the

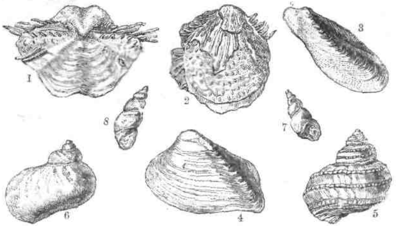
ultimate grouping of all the members of the system. Among the PLANTS, which, as already stated, have less or more a carboniferous aspect, we may notice the fucoids, *chondrites* and *polysiphonia*; the filicoids, *caulerpa*, *neuropteris*, *pecopteris*, *sphenopteris*, and other ferns closely allied to those of the coal-measures; the reed-like plants, *calamites*, *equisetites*, and *asterophyllites*; and the coniferous-looking stems and branches known as *lycopodites*, *lepidodendron*, and *walchia* (after Walch). Fossil fruits, as the *cardiocarpium* (heart-shaped), are not uncommon; while leaves like those of the fan-palm and cycas, known by the name of *nœggerathia* (after Nœggerath), and silicified trunks of tree-



1, Walchia piniformis; 2, Nœggerathia cuneifolia

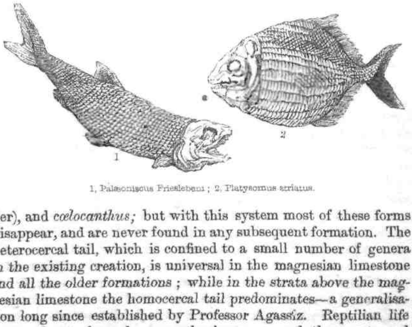
ferns, termed *psaronites*, are characteristic features of the Permian flora. Of ANIMAL remains, we have in certain localities a fair proportion of marine types in the magnesian limestone, though we altogether miss that profusion of corals, encrinites, and molluscs, which crowded the waters of the mountain-limestone epoch. Of spongiform organisms we may mention *mammillopora* (pap-pore) and the *bothroconis* (pitted-cone); of corals, the *calamopora* (reed-pore), *aulopora* (pipe-pore), *calophyllum* (beautiful leaf), and *alveolites* (*alveus*, a pipe or channel); and of the minute foraminifera we have the tooth-like *dentalina* and *textularia*. Of echinoderms we have still the *cyathocrinite* and *archæocidaris*; of vermiform organisms, *spirorbis* and *serpula*; and of crustacea, the *cythere* and *dithyrocaris*. The trilobite, however, has disappeared, and we have none of the curious complex crustacean forms that characterised the Devonian and carboniferous epochs. Of mollusca, we may notice the compound forms *fenestella* and *phyllopora*; the brachiopods, *lingula*, *producta*, *strophalosia*, and *trigonotreta*; the dimyarian bivalves, *mytilus*, *Bakevellia*, *schizodus*, and *byssoarca*; the gasteropods,

rissoa, *natica*, and *pleurotomaria*; and one or two *cephalopods*



1 Productus horridus; 2, Strophalosia Morrisiana; 3, Bakevellia Sedgwickiana
4, Schizodus Schlotheimi; 5, Turbo helicinus; 6, Natica Leibnitziana;
7, Rissoa Leighi; 8, Macrocheilus symmetricus.

resembling the *nautilus*. Of fishes we have several of the smaller ganoid forms, as *palæoniscus*, *pygopterus*, *platysomus* (broad-shoul-



1, Palæoniscus Frieslebeni; 2, Platysomus striatus.

der), and *cœlocanthus*; but with this system most of these forms disappear, and are never found in any subsequent formation. The heterocercal tail, which is confined to a small number of genera in the existing creation, is universal in the magnesian limestone and all the older formations; while in the strata above the magnesian limestone the homocercal tail predominates—a generalisation long since established by Professor Agassiz. Reptilian life seems also to have been on the increase; and the scanty and somewhat doubtful forms of the old red and coal-measures are now succeeded by true air-breathing, land-inhabiting creatures of the frog and lizard families, whose peculiar conical, compressed,

and finely-serrated teeth, bones, and footprints, have been found in Russia, Germany, and the south-west of England—if we are to regard the Bristol dolomitic conglomerate of Permian rather than of Triassic epoch. Of these Lacertilians the *palæosaurus* (ancient saurian), *protorosaurus* (first saurian—a name applied before reptilia had been discovered in the older strata of the coal-measures), and *thecodontosaurus* (sheath-tooth saurian), are perhaps the most characteristic—the latter being allied to the living monitor; and, as Professor Owen has observed, "its appearance in palæozoic strata is opposed to the doctrine of progressive development of reptiles from fish, or from simpler to more complex forms; for if it had existed at the present day, it would take rank at the head of the Lacertian order." As a family, the thecodont saurians seem peculiar to the Permian or Lower New Red Sandstone—as peculiar, indeed, to the system as the ichthyosaurs are to the Lias and Oolite. Within the last three or four years, remains of small marsupial quadrupeds have been detected in the Red Sandstones of Virginia and North Carolina—strata which by some are regarded as Triassic, and by others as the equivalents of our European Permians; but as these will be better considered in connection with the mammalian remains of the Trias, we defer their consideration till we treat of the fauna of that epoch.

Geographical and Physical Features.

221. The geographical area over which rocks of the Permian epoch are spread is by no means well defined. All the red sediments that occur above the coal being hitherto regarded as *new red sandstone*, and there being after all a great similarity, lithologically speaking, between the whole suite, it is no easy task, unless where the fossils are abundant and distinct, to lay down the exact boundaries of the Permian and Triassic. In the northern and midland counties of England, where the magnesian limestone is well developed, there is generally little difficulty in deciding; but in the western and southern districts, as well as in the south-west of Scotland, and over certain areas in North America, it is often impossible, in the absence of fossils, to say what is Permian and what Triassic. On the whole, considerable areas of England, of Ireland, of France, of Germany, and America, are occupied by undoubted Permians, while almost the whole of eastern Russia is one unbroken development of the system.

222. The igneous rocks associated with the system are chiefly dykes and outbursts of basalt, greenstone, pitchstone, and claystone porphyry. These outbursts seem to be connected with

igneous centres situated in the older systems, and pass alike through the old red, carboniferous, and new red systems. With the exception of some tufaceous and brecciated beds at the base of the system, there appear to be few interstratifications of igneous matter; and, on the whole, the Permian era, within the area of Europe at least, seems to have been one of comparative tranquillity. Immediately before its deposition, the igneous centres of the coal-fields were in a state of intense activity; and to the frequent upheavals and submergences that then took place, may be ascribed, perhaps, the rapid accumulation of the red sediments of the Permian epoch. At all events, we have comparative paucity both of animal and vegetable life; rivers charged with oxidated waters; and seas in conditions peculiarly favourable to the formation of saline, gypseous, and magnesian sediments. As will be seen in the Recapitulation, chemistry has not yet been able to throw much light on the conditions favouring such extensive accumulations of rock-salt, gypsum, and magnesia; nor are geologists at all agreed about the origin of the breccias and conglomerates that occur in the system. The convulsive movements of repeated earthquakes have been called in to account for the fracturing and reconsolidation of the Tynemouth brecciated or pseudo-brecciated limestones; so also have peculiar chemical and physical forces; and recently the transport by ice, and the external conditions of an arctic climate, have been suggested by Professor Ramsay as connected with the accumulation of the Permian breccia-conglomerates of Salop and Worcester.

[Professor Ramsay, who was the first to advocate, in a decided manner, the glacial origin of these breccias, founds his belief on the following evidences:—1. The great size of many of the fragments—the largest observed weighing (by a rough estimate) from a half to three-quarters of a ton. 2. Their forms. Rounded pebbles are exceedingly rare. They are angular or sub-angular, and have those flattened sides so peculiarly characteristic of many glacier-fragments in existing moraines, and also of many of the stones of the pleistocene drifts, and the moraine matter of the Welsh, Highland, Irish, and Vosges glaciers. 3. Many of them are highly polished, and others are grooved and finely striated, like the stones of existing Alpine glaciers, and like those of the ancient glaciers of the Vosges, Wales, Ireland, and the Highlands of Scotland; or like many stones in the pleistocene drifts. 4. A hardened cementing mass of red marl, in which the stones are very thickly scattered, and which in some respects may be compared to a red boulder-clay, in so far that both contain angular, flat-sided, and striated stones, such as form the breccias wherever they occur.—*Journal of Geological Society*, vol. xi.]

223. The physical geography of Permian districts, though devoid in a great measure of those eruptive undulations and eminences which give character to the scenery of the mountain limestone and old red sandstone, is by no means destitute of beauty and variety. The soft marls and partially consolidated sandstones

admit of easy erosion by streams and rivulets, and thus we have a succession of gentle slopes and rounded eminences, which produce a pleasing, if not a picturesque, landscape. Unless immediately over the magnesian limestone, the soil of Permian districts is generally a red clayey loam, better adapted for pasture and woodland than for the rotation of mixed husbandry. In England, the eastern portions of Durham, middle Yorkshire, Nottingham, and the district round Shrewsbury, may be taken as the types of Permian scenery.

Industrial Products.

224. The industrial products of the system, though not to be compared with those of the coal-measures, are still of considerable importance. The sandstones and conglomerates are quarried in many districts for building purposes, as are also some of the magnesian limestones, which, like that of Bolsover in Derbyshire, employed in the construction of the new Houses of Parliament, dress well, and in the carefully selected beds are exceedingly durable, while in others less carefully chosen, wasting and disintegration often show themselves in less than a dozen years. The limestones are likewise used in agriculture, and as mortar for the builder, while certain of the compact fissile varieties furnish not indifferent blocks for the lithographic printer. Gypsum is an abundant product of some of the marls; while in Germany the dark bituminous-looking schist, known as the *kupfer-schiefer*, has been long mined as an ore of copper, and furnishes a large proportion of that valuable metal. Veins of galena and sulphuret of zinc occasionally traverse the magnesian limestones, but, on the whole, the system is not noted as a repository of the metals.

NOTE, RECAPITULATORY AND EXPLANATORY.

225. The system above described consists essentially of reddish sandstones and brecciated conglomerates, yellowish magnesian limestones and slaty calcareous beds. From the prevailing hues of its strata, and from the fact of its lying immediately above the coal-measures, it has been termed the *new red sandstone*, in contradiction to the old red, which lies beneath. Along with the saliferous marls and variegated sandstones of the triassic strata above, it was early observed to hold a sort of middle place among the secondary formations; hence the lias, oolite, and chalk above

were considered as *younger* or *upper secondaries*, while the new red, the carboniferous strata, and the old red, were termed the *older* or *lower secondaries*. From the fact of the lower members of the new red sandstone containing fossils more or less allied to carboniferous types, and its upper members imbedding those less or more allied to oolitic forms, it has been proposed to separate them into two distinct systems—the *Permian* (from Perm in Russia, where it is extensively developed), and the *Triassic*, regarding the triple group of Germany as typical of its upper strata. Adopting this view, we have the following synopsis :—

	Germany.	*England.*
TRIAS.	Keuper.	Saliferous marls and grits.
	Muschelkalk.	(*Wanting.*)
	Bunter sandstein.	Variegated sandstones.
PERMIAN.	Lower bunter.	Gypseous marls and grits.
	Zechstein.	Magnesian limestone.
	Kupfer-schiefer.	Marl slate.
	Rothe-liegende.	Red sandstones.

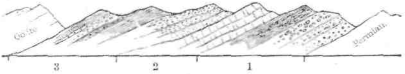
In the Permian, the fossils are plants akin to those of the coal-measures, with crinoids, shell-fish, fishes with heterocercal tails, and frog-like reptiles. In the Trias, as will be seen in the next chapter, the plants resemble oolitic types, and the animal remains are corals, encrinites, shell-fish, fishes with homocercal tails, amphibious reptiles, and traces of birds. Taking the whole composition, succession, and remains of both systems, they indicate a period of shallow seas supercharged with saline matter, of muddy estuaries and lagoons, of frequent submergences and upheavals, and of peculiar climatal influences, which, while it favoured the rapid distintegration and transport of rock-matter, does not seem to have been congenial to a luxuriant development of vegetation. During the period many forms of life disappeared, and were succeeded by others of a different type and order; hence the Permian group is regarded as *palæozoic*, and the triassic as *mesozoic*.

Origin of Magnesian Limestone.

226. As in the case of coal, rock-salt, flint, and other rocks whose formation cannot be satisfactorily accounted for by the ordinary conditions of mechanical sediment, the origin of the magnesian limestone has given rise to much ingenious speculation. The most prevalent hypotheses are—*first*, that the magnesian limestones were produced by the chemical union of carbonates of lime and magnesia which were deposited in a state of admixture from the waters of seas and lakes; and, *secondly*, that their forma-

tion is due to the metamorphism of ordinary limestones. There are difficulties, no doubt, in the way of both hypotheses, but the former is that which admits of most extensive and satisfactory application. "The circumstances," says Professor Phillips, "which permitted the accumulation of the magnesian carbonates of lime, are in a great measure unknown to us. That they were originally deposited in the same chemical condition as we now see them, without the subsequent aid of any igneous operations, is perfectly evident. It has been imagined, because certain beds of the carboniferous limestone contain a large proportion of magnesia, that the one is derived from the ruins of the other. But, as Professor Sedgwick observes in discussing this subject, all the magnesian beds in the carboniferous limestone would be quite insufficient for the purpose, and the *crystalline character* of the Mansfield and other varieties of magnesian limestone clearly negatives this mechanical solution. Beds rich in magnesia alternate with others devoid of that substance; the same beds are in one tract magnesian, in another yield pure lime; and in general we must be content to shelter our ignorance under the statement—*that, from some unknown cause, the waters of the sea were then decomposed in such a way as to permit very generally the precipitation of united magnesian and calcareous carbonates; the possible circumstances of which must be intrusted to the examination of the chemist.*" Chemically, the subject has been recently and fully examined by Mr Hunt of the Canadian Geological Survey, who also arrives at the conclusion that magnesian limestones are due to the chemical union of carbonates of lime and magnesia in the waters of deposit, and not to a subsequent metamorphism of ordinary sedimentary limestones.

227. For further elucidation of the system — whose limits, whether geographically or lithologically, are by no means well defined—we refer the inquiring student to the *Memoirs and Maps of the Geological Survey;* to Professor Sedgwick's *Memoir*, in the *Geological Transactions;* to King's *Monograph of Permian Fossils*, in the publications of the Palæontographical Society; to the *Geology of Russia*, by Sir Roderick Murchison; to the *Siluria* of the same author; to a paper on the supposed glacial origin of the Permian Breccias by Professor Ramsay, in the eleventh volume of the *Geological Journal;* and to a recent communication by Mr Kirkby, in the same publication, on the *Permian Rocks and Fossils of South Yorkshire.* On the formation of gypsums, magnesites, and dolomites, the student may consult Mr Sterry Hunt's elaborate and ingenious paper in the twenty-eighth volume of *Silliman's American Journal.*



XIV.

THE TRIASSIC SYSTEM:

COMPRISING—1, THE BUNTER SANDSTEIN; 2, THE MUSCHELKALK; AND, 3, THE KEUPER OF GERMANY; OR UPPER NEW RED SANDSTONE OF ENGLAND.

228. THE reasons for separating what was formerly known as the "New Red Sandstone" into two distinct systems—the *Permian* and *Triassic*—have been stated in the preceding chapter. Before this division, it was usual to arrange the new red sandstone, as developed in England, into upper, middle, and lower groups—the *upper* comprising the saliferous marls and variegated sandstones of Cheshire; the *middle*, the magnesian limestones of York and Durham; and the *lower*, those reddish sandstones and grits which immediately overlie the coal-measures in the north of England. The succession of the strata composing the lower and middle groups has been already tabulated in paragraphs 216 and 218; the following briefly exhibits the lithology of the upper group as usually developed in England:—

VARIEGATED MARLS.—Red, with bluish, greenish, and whitish laminated clays or marls holding *gypsum* generally, and *rock-salt* partially (as in Cheshire). Interstratified with these marls are certain grey and whitish sandstones ("water-stones").

VARIEGATED SANDSTONES.—Red sandstones, with white and mottled portions; the lower strata in some districts pebbly, in others gritty breccias and conglomerates.

In addition to these marls and sandstones, there is developed on the Continent a considerable thickness of shelly fossiliferous lime-

stone known as the MUSCHELKALK; and when this is interpolated, the upper new red consists of three well-marked members; hence the *Trias*, or triple system of German geologists. Tabulated in descending order, the following exhibits the equivalents of the system as developed in Germany and England :—

	Germany.	*England.*
1. KEUPER.	Saliferous and gypseous shales, with beds of variegated sandstones and carbonaceous laminated clays.	Saliferous and gypseous marls, with grey and whitish sandstones.
2. MUSCHELKALK.	Compact greyish limestone, with beds of dolomite, gypsum, and rock-salt.	(*Wanting.*)
3. BUNTER SANDSTEIN.	Various coloured sandstones, dolomites, and red clays; occasional pisolites.	Reddish sandstones and quartzose conglomerates.

229. The student will thus perceive that the Triassic system, where fully developed, consists of three main groups—1, The Keuper (saliferous marls and grits); 2, the Muschelkalk (shelly limestone); and, 3, the Bunter Sandstein (variegated sandstones). Of course, in different districts the lithology of these groups will be found to vary, though the persistence of saliferous grits and marls in the upper portion of the system, and of variegated sandstones in the lower, over wide areas in England, France, and Germany, is perhaps one of the best established facts in geology. In England the most typical Triassic district is perhaps the salt region of Cheshire, in which Mr Ormerod finds the total thickness of red sandstones and marls to be at least 1700 feet, of which the upper group, including the salt and gypsum, takes about 700 feet; the middle group, containing laminated sandstones, called "Water-stones," 400 feet; and the subjacent sandstones, mostly red and partially conglomeritic, believed to correspond with the "Bunter Sandstein" of Germany, 600 feet. Taking the fullest development, as indicated by the sections of the Geological Survey, the English Trias presents, in descending order, the following well-defined members :—

KEUPER.	1. Mottled (grey, green, and red) clays and marls. 2. Red marls, with sandy laminæ and sandstones. 3. Red and blue clays, with rock-salt and gypsum. 4. Water-stones (laminated sandstones).
BUNTER.	5. Soft red variegated sandstone. 6. Coarse red sandstone and conglomerate. 7. Soft red and variegated sandstone.

On the Continent the typical members may be arranged in the same manner, as follows :—

KEUPER.	1. Variegated marls (red, blue, and green), with gypsum and sandy layers. 2. *Red and dark marls, with gypsum and limestone layers.*
MUSCHELKALK.	3. Greyish fossiliferous limestone, with marl partings. 4. *Compact magnesian limestone.*
BUNTER.	5. *Soft variegated sandstones.* 6. Coarse-grained and conglomeritic sandstones.

230. Co-ordinating the English with the Continental strata, as far as present data will permit, we have the following relations:—

England.	*Germany.*	*France.*
Variegated Marls.	Keuper.	Marnes orisées.
...	Muschelkalk.	Calcaire coquillier.
Variegated Sandstone.	Bunter Sandstein.	Grès bigarré.
...	...	Grès des Vosges.

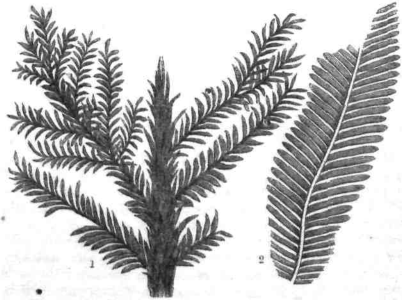
In America, more especially in the states of Massachusetts and Connecticut, there is also an extensive development of red sandstones, shales, and conglomerates, evidently posterior in formation to the coal, but not yet very clearly separable into Permian and Triassic. As far as fossil evidence goes in the mean time, the fishes and footprints seem rather indicative of the Triassic epoch, and to this view American as well as British geologists have for some time given their assent. Lithologically, the American strata are extremely similar to those of the Mersey and Solway, and in their composition and arrangement point prominently to a similarity of external conditions and modifying agencies during the period of their deposition.

Palæontological Characteristics.

231. Speaking with that reserve which a progressive science like geology necessarily imposes, the Life of the Trias, as known in the northern hemisphere, may be described as scanty, and only developed round limited and distant centres. In the vegetable world we miss that variety of form and profusion which characterised the coal-measures, died away under the Permian epoch, and again revived during the deposition of the lias and oolite; while in the animal world, though the era is marked by the introduction of new and higher forms, it by no means exhibits either extensive distribution, numerical amount, or variety of species. How and why this paucity of life, geology is yet unable to determine; though this much is certain, that a great series of elevations and depressions had taken place—old lands had passed away

and new ones risen from the bottom of the deep, and over the whole were imposed other influences of climate and external condition. All this necessarily implied new centres of creation and dispersion, and altered forms to harmonise with the new conditions of existence. Thus arose the flora and fauna of the Trias—a flora and fauna more allied to those of the oolite and chalk than to those of the coal-measures and old red sandstone; and hence the reason for regarding the Trias as *Mesozoic*, while the Permian has been included within the great *Palæozoic* cycle.

232. From whatever cause it may have arisen—the unfitness of the dry land to nourish an exuberant vegetation, or the unfitness of the new red sediments to preserve it in a fossil state—there can be no doubt of the fact, that the Triassic flora is one extremely limited, both in numerical amount and variety of species. In Britain, the system is almost destitute of vegetable remains, and it is chiefly in Continental and American strata that the characteristic types have been detected. There are several species of equisetum and calamite, among which the *E. columnare* and *C. arenaceus* are the most characteristic; a larger variety of filicoid plants, as *pecopteris Meriani*, *tæniopteris vittata*, *neuropteris Voltzii* and *elegans*, *sphenopteris myriophyllum*, and



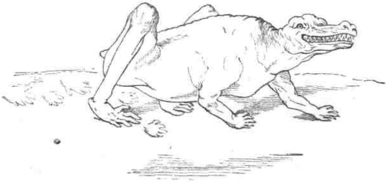
1. Walchia; 2, Pterozamites or Pterophyllum, from North America.—Emmons.

filicites scolopendrioides; a few cycadeaceous plants, as the *pterophyllum* and *Mantellia;* some fragments of unknown affinity, as

the *convallarites* and *echinostachys*; the pine-like *Voltzia*, apparently peculiar to the Trias, of which the *brevifolia*, *elegans*, and *heterophylla* are the most abundant; the *Walchia hypnoides*; and the doubtful dicotyledonous-looking leaf, *dictyophyllum crassinervum*. On the whole, the student cannot fail to perceive that the Triassic flora exhibits much more of an oolitic than of a carboniferous aspect; and that the sigillaria, stigmaria, and lepidodendra of palæozoic epochs have given place to forms more nearly allied to the tree-ferns, cycads, zamias, palms, and sub-tropical pines of the present era.

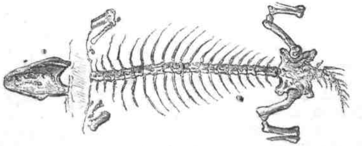
233. When we turn to the Fauna, we find the same mesozoic aspect prevailing, together with the introduction of higher and terrestrial forms. We have none of the curious corals of the silurian and mountain limestones, comparatively few encrinites, the productæ and their allies have disappeared, no trilobites or strange-looking cumoid crustacea, no bone-encased fishes, and now no universal heterocercal developments. Nature has commenced another cycle, and with this movement the palæontologist is presented with other species and newer phases of vitality. As yet the muschelkalk is the great storehouse of triassic marine life, and in it we find several starfishes, as *ophiura prisca*, *aspidura loricata*, and *asterias obtusa*; and one well-marked and abundant encrinite, the *e. liliiformis*. Of bivalve mollusca, we may notice as common in the same strata *cardium pectinatum*, *trigonia vulgaris* and *levigata*, *mya musculoides* and *elongata*, *mytilus vetustus*, *plagiostoma lineatum* and *punctatum*, *avicula socialis*, one of the most characteristic shells in the system, *possidonia keuperiana*, *astrea* several species, *pecten reticulatus*, and *terebratula communis* and *subrotunda*. Of the gasteropods, we have *calyptræa*, *trochus*, and *turitella*; and of cephalopods, the *nautilus bidorsatus* and *ceratites nodosus*. These cephalopods mark well the transition between the plain-sutured chambered-shells of the mountain limestone, and the ammonites with foliated sutures so abundant in the lias and oolite—in other words, between the *palæozoic* and *mesozoic* species of the same great order. Of Fishes, now that the "bone-bed" of Aust and Axmouth has been separated from the lias and ranked as upper triassic, we have numerous species; that is, if we regard the different teeth, scales, and fin-spines as really indicative of distinct species. Of these we may notice the conical shark-like teeth of the *saurichthys* (sauroid-fish), the *gyrolepis* (twisted-scale), *acrodus* (pointed-tooth), *ceratodus* (horn-tooth), and *hybodus* (hump-tooth). Of Reptilia, the remains of several curious genera have been found throughout the system, both in England

and Germany, but much more perfect data are wanted to enable the palæontologist to arrive at an accurate knowledge of their zoological affinities and functions. Of these we may notice the frog-like *labyrinthodon* (so called from the labyrinthine-like



Restored form of Labyrinthodon, with footprints the same as Cheirotherium.

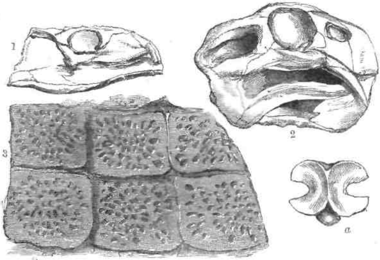
structure of its teeth), the *phytosaurus* (plant-saurian), the *nothosaurus* (doubtful saurian), the *thecodontosaurus* (sheath-tooth saurian), the *rhynchosaurus* (sharp-nosed saurian), the small lizard-like *telerpeton* of the Elgin sandstones, which are now re-



Telerpeton Elginense.

garded as of Triassic age, the larger *hyperodapedon*, and the crocodilian-like *staganolepis* of the same formation. To these may be added the *Dicynodont* reptiles from the red sandstones of Southern Africa and Bengal, which are also regarded as the equivalents of our European Trias. The principal remains of these curious reptiles yet discovered, are the bones of the head, which seem to indicate a gigantic type between the lizards and turtles. The eye orbits are very large, the cranium flat, with nostrils divided as in lizards; and the jaws toothless, with the exception that the upper jaw possesses a pair of long tusks, implanted in sockets and

turned downwards like those of the walrus—hence the name *dicynodon* or " two canine teeth."



1. Rhynchosaurus articeps; *a*, vertebra of do.; 2, Dicynodon lacerticeps; 3, Scutes of Stagonolepis.

234. Besides the teeth and bones of these early reptiles, we have also their footprints impressed and preserved on the slabs of sandstone, almost as clearly as if they had traversed the muddy beach of yesterday. These footprints speak a language similar to that of the ripple-mark and the rain-drop formerly alluded to—the foot leaving its impress on the yielding and half-dried mud, and the next deposit of sediment filling up the mould. On splitting up many of these slabs of sandstone, the mould and its cast are found in great perfection—so much so, that not only the joints of the toes but the very texture of the skin is apparent. These fossil footprints, termed *ichnites* (from *ichnon*, a footstep), have been found at Corncockle Muir in Dumfriesshire, at Storeton in Cheshire, at Hildburghausen in Germany, on the Connecticut in America, and many other places. Some of them are evidently reptilian, hence termed *sauroidichnites*; some, again (judging from their form, the texture of the epidermal impressions, and the amount of uric acid contained in the coprolites that are usually associated with them), appear to be those of gigantic birds allied to the ostrich, and thence termed *ornithichnites* (*ornis*, a bird); while others appear to be those of unknown quadrupeds (in all likelihood of some huge batrachian or frog-like reptile), and have received the provisional designation of *tetrapodichnites*, or four-footed imprints. When occurring in

single lines these footprints are spoken of as *uniserial*, and are evidently the tracks of two-footed creatures; when in double lines they are termed *biserial*, and as clearly indicate the passage of some four-footed animal. The annexed engraving represents the biserial footsteps of the *cheirotherium* (*cheir*, the hand), so called from the hand-like impressions of its feet, and is supposed by Professor Owen to be one and the same with the batrachian or frog-like labyrinthodon. *Ichnology*, as the science of fossil

Footprints of Cheirotherium.

footprints may be termed, has now become a favourite study with several geologists; and though such imprints occur both in the old red sandstone and the coal-measures, the slabs of the new red have hitherto yielded them in the greatest variety and distinctness. Indeed, so abundant are they on the Connecticut river sandstones, which are mainly Triassic (the upper beds being of the age of the Lias, and the lower perhaps Permian), that Dr Hitchcock has already enumerated 123 species—viz., marsupialoid animals, 5 species; birds, 31 species; ornithoid reptiles, or reptiles walking on their hind-feet, 12; lizards, 17; batrachians, 16; chelonians, 8; fishes, 4; crustaceans, myriapods, and insects, 17; and annelids, 10. It is to such local developments of *ichnites* that we are mainly indebted for the instructive *Ichnology of New England* by Professor Hitchcock, the superb *Ichnology of Annandale* of Sir William Jardine, and the equally magnificent lithographs by Professor Lea of the *Fossil Footsteps in the Red Sandstones of Potsville, Pennsylvania.*

235. Of a still higher type of being than is indicated by these footprints are the mammalian molar teeth and fragments of bone discovered some years ago (1847) by Professor Plieninger in the bone-breccia of Wurtemburg—a stratum which occurs among the upper beds of the Keuper, and occupying nearly the same place in the system as the celebrated "bone-bed" of Aust and Axmouth. These remains, according to the determinations of Dr Jäger, Mr Waterhouse, and Professor Owen, are those of a warm-blooded quadruped—the earliest of its kind yet detected in the crust of the earth, and probably insectivorous. From this circumstance, and the diminutive size of the teeth, the creature has received the

provisional name of *Microlestes antiquus* (*micros*, little, and *lestes*, a beast of prey). More recently, analogous remains (the *Dromatherium silvestre*, or running beast of the woods) have been de-

Jaw of Dromatherium silvestre, from the Red Sandstones of North Carolina.—Emmons

tected by Mr Emmons in the Red Sandstones of Virginia and North Carolina—strata which by some are regarded as Triassic, and by others as the equivalents of our European Permians. And more recently still (1860), Mr Moore of Bristol has discovered in triassic drifts numerous teeth and other mammalian remains indicative of new genera, thus adding most important links to that gradually lengthening chain which is yearly connecting the Past more intimately with the Present, and compelling geologists to dogmatise less rashly regarding the creational introduction and progress of vitality.

Physical Aspects.

236. Strata, as above described—that is, strata composed of reddish clays and marls, containing deposits of rock-salt and gypsum, of greyish shelly limestones, and variegated sandstones, and pebbly grits—are found occupying considerable areas both in the Old and New Worlds. They occur in patches on the western coasts and islands of Scotland, on the opposite coast of Ireland, in the basin of the Solway, and southward in more or less determinate areas to the Mersey, where the formation merges into that broad and noticeable belt of red sediments which stretches diagonally across the whole of England, from Durham on the one hand to South Devon on the other. On the Continent it occupies still wider areas, as in Eastern France, Southern and Northern Germany, and in the region of the Alps; while some of its most instructive features are exhibited in the states of Massachusetts and Connecticut in North America. Red sandstones and marls apparently of the same age occur also in Arabia, Upper Egypt, Persia, along the Indus, in New Holland, and in Central and Southern Africa.

237. The igneous rocks associated with the system are identical

with those that break through and displace the Permian strata—being dykes and eruptive masses (no tufaceous interstratifications being known) of augitic greenstone, basalt, pitchstone, and pitchstone-porphyry. On the whole, triassic districts are little varied by trap eruptions, while the predominance of clays, shales, and soft sandstones, which have yielded readily and uniformly to subsequent denudation, gives rise to broad level expanses, rather tame and uninteresting in their superficial features. "Spread over so immense a space in England," says Professor Phillips, "the triassic system offers the remarkable fact of never rising to elevations much above 800 feet—a circumstance probably not explicable by the mere creating of these soft rocks by floods of water, but due to some law of physical geology yet unexplained. We only can conjecture that it is connected with the repose of subterranean forces which prevailed after the violent commotions of the coal strata, over nearly all Europe, till the tertiary epoch."

238. Large areas of Lancashire, Cheshire, and Stafford, partake of this flat and uninteresting character; and such, no doubt, is the general physical geography of the system. Still, there are triassic districts on the verges of the older formations, as in Shropshire, in Warwick, and South Devon, whose tumbling undulations and verdant slopes are far from devoid of beauty and amenity. Over the sandstones of the system the soil is occasionally light, and of little value (Warwick, Nottingham), and the retentive shales sometimes form the bases of extensive morasses (South Lancashire); but generally speaking the decomposed marls have given rise to a stiff but not unfertile clayey loam, apparently better fitted for pasture (Cheshire, the vales of Taunton and Exeter) than for the requirements of tillage and corn culture.

239. Reviewing the whole new red system—its sandstones, shales, magnesian limestones, gypseous, saliferous, and cupriferous marls, its comparatively few plants, its marine shells and fishes, its reptiles and fossil footprints, and its generally flat and undisturbed position—we are reminded of quiet shallow seas, of iron-tinged rivers, and of estuaries studded with lagoons and mud-banks. The finely-laminated marls and copper slates give evidence of tranquil deposit; the footprints, of mud-banks dried and baked in the sun, over which birds and reptiles traversed till the next return of the waters; the gypsum, rock-salt, and magnesia, of highly saline waters, subjected to long-continued evaporations, or at least to some chemical conditions (see Recapitulation) favourable to the precipitation of these abundant salts; and the presence of iron, colouring less or more the whole strata, together with copper in many of the slates, points to impregna-

tions by no means favourable to the exuberance of marine life. The remains of arborescent ferns, cycadeaceous and palm-like stems, together with the skeletons and tracks of huge lizard-like reptiles, bespeak an arid rather than a genial climate, and a want of those conditions which gave birth to the exuberant vegetation of the coal era.

Industrial Products.

240. The industrial products yielded by the system are sandstones of various quality, calcareous flagstones, limestone, gypsum, and rock-salt. Our chief supply of salt, formerly obtained by evaporation of sea-water, is now procured from the salt-mines and brine-springs of Cheshire and Worcester, which annually yield, on an average, from 160,000 to 170,000 tons of prepared and purified salt. "*The Cheshire deposits of salt lie along the line* of the valley of the Weaver, in small patches, about Northwich. There are two beds of rock-salt lying beneath 120 feet of coloured marls, *in which no traces of animal or vegetable fossils occur.* The upper bed of salt is 75 feet thick: it is separated from the lower one by 30 feet of coloured marls, similar to the general cover; and the lower bed of salt is above 100 feet thick, but has nowhere been perforated. Whether any other beds lie beneath those is at present unknown. They extend into an irregular oval area, about a mile and a half in length, by three quarters of a mile in breadth." The salt in these deposits is sometimes pure and transparent, and at other times is of a dirty reddish hue, and mixed to the amount of half its bulk with earthy impurities. It *is not stratified or laminated, but divided into vertical prisms of* various forms and magnitudes, sometimes more than a yard in diameter—the outer sides of these rude crystallisations being generally pure and transparent. The *brine* or *salt springs* which often issue from these deposits, contain $3\frac{1}{2}$ to $6\frac{1}{2}$ per cent of salt, and are doubtless derived from the solution of the solid masses by subterranean waters.

NOTE, RECAPITULATORY AND EXPLANATORY.

241. The system described in the preceding paragraphs consists *in the main of reddish clays and marls usually saliferous, of shelly* laminated limestones more or less magnesian, and of variegated

red and whitish quartzose sandstones, with occasional beds of pebbly conglomerate. Briefly tabulated, it exhibits in England and on the continent of Europe the following well-marked series :—

England.	*Germany.*	*France.*
Variegated marls.	Keuper.	Marnes irisées.
...	Muschelkalk.	Calcaire coquillier.
Variegated Sandstones.	Bunter Sandstein.	Grès bigarré.

It has received its name, TRIAS or TRIASSIC, from being composed of the three members so clearly developed in Germany, while the synonyme "UPPER NEW RED" is sufficiently distinctive of its place among English strata. Its fossils are all of *Mesozoic* types, and though a few point to Permian analogues, the identities, if identities there be, are to be sought among Oolitic rather than among Palæozoic strata; hence the reason of its separation as an independent life-period from the great "new red sandstone formation" of the earlier geologists. Though the accumulation of such masses of rock-salt (chloride of sodium) be still in some measure an unsolved problem, their occurrence in conjunction with gypsum (sulphate of lime) and with magnesian limestones (carbonates of magnesia and lime), less or more, throughout the whole new red sandstone system, would seem to indicate peculiar marine conditions—conditions of shallow land-locked bays and lagoons, periodical isolation of certain areas, and again their submergence and reception of ferruginous mud and clay-silts. Over the entire area there are no marked manifestations of igneous action, and yet the abundance of red sediments, the peculiar chemical composition of many of the strata, and the frequent oscillations of level, would seem to indicate the existence of such agencies, if not in a suppressed condition, at least in terrestrial centres at considerable distance from the seas of deposit. The prevalence of red saliferous sediments and the almost total absence of marine exuviæ from such strata, are among the most noted features of the system; and yet nothing can be clearer than the oceanic nature of the deposit, and the long-continued action of waves and currents in assorting and arranging its material. To account for this apparent anomaly, we must suppose either that the waters were too highly charged with saline and mineral ingredients to permit of the development of life, or that the nature of the strata was unfitted for their subsequent preservation. Whichever view is taken, the fact remains, that Triassic strata are only fossiliferous over partial areas; and hence the difficulty of determining to which epoch (Permian or Triassic) many red sandstones and marls do really belong. The nature of the imbedded

plants and animals, so far as their paucity will permit us to decide, appears to point to a somewhat hot and arid climate—to insular rather than to continental areas of dispersion—to shallow estuaries, lagoons, and mud-banks, where gigantic wading-birds and amphibious reptiles found subsistence on shell-fish, crustacea, star-fishes, and fishes, and left their tracks on the sun-baked mud, as evidence of their forms and of the kind of life they led on the shores of these primeval waters.

Origin of Rock-Salt.

242. As already stated, the formation of such chemico-mechanical precipitates as rock-salt, gypsum, and magnesian limestone, has given rise to a great deal of ingenious speculation and hypothesis. The chemical difficulties connected with the origin of dolomite have been noticed in the preceding chapter (par. 226); the formation of rock-salt remains much in the same scientific predicament. The sandstones and marls with which it is associated—exhibiting as they do the lines and laminæ of deposition—are evidently the result of sediment in water; but the irregularity of the salt beds, their variable thickness, uneven surfaces, rude prismatic crystallisation, and capricious occurrence among the other strata of the system, as well as the soluble nature of the compound, all point to a somewhat different origin. At present, salt lakes and superficial accumulations of salt occur in various parts of the world, and these in some measure supply data for reasoning as to the saliferous deposits of earlier eras. Salt lakes, brine pools, and salinas are supplied chiefly by saline springs, and being subjected to the vaporising influence of the sun, which carries off only *fresh* vapour, their waters become in time supersaturated with saline matter, or it may be desiccated entirely—leaving incrustations of various thickness, as in the salt lakes of Asia Minor, and along the coasts of India; in the natron beds of Africa; and the salinas (nitrates and muriates of soda) of South America. But even where entire desiccation does not take place, water can only hold a fixed amount of salt in solution; and so soon as this amount is attained, the salt begins to fall to the bottom by its own gravity. In the course of ages, these layers will form a thick bed, interstratified, it may be, with mud or other earthy sediment, and if the lake or valley be ultimately filled up, the salt (subjected to pressure and internal crystalline arrangement) will constitute a mass precisely analogous to the rock-salt of the new red sandstone. Such is the process which many geolo-

gists have advanced to account for the formation of rock-salt. Supposing that, in addition to the local accumulations of salt lakes and salinas, certain areas or lagoons were occasionally cut off from connection with the main sea of deposit, and subjected to a rapid evaporating power without receiving fresh accessions of water, repetitions of this process, arising either from periodical overflows, or successions of elevations and submergences, are sufficient to account for the thickest accumulation. According to this view, the repetitions and thickness of the rock-salts, marls, and sandstones become a mere question of time — an element which knows no limit, and can only be roughly guessed at by the magnitude of geological operations. The circumscribed areas of rock-salt basins, and the capricious thickness of the beds, seem to favour such a theory; and when we consider the frequency of disturbance by subterraneous forces in earlier ages, and the fact of many of these deposits occurring near to or in connection with axes of elevation, it is more than probable that igneous action had to do with their formation. If such were the origin of rock-salt, it must have been formed during the deposition of other systems; and this geological research has confirmed, for although the most extensive accumulations in England occur among the sandstones and shales of the system under review, deposits of equal magnitude are found in connection with oolitic strata as in the Salzburg Alps, with cretaceous greensands as at Cordova in Spain, with chalk and tertiary rocks in the valley of Cardona in the district of the Pyrenees, with tertiary marls as in Sicily and at Wielitska in Poland; and salt springs are known to issue from carboniferous, Devonian, and older strata.

243. Notwithstanding these facts, it must be admitted that Geology has not yet arrived at an altogether satisfactory theory. The great thickness of some of the salt beds, their comparative purity and homogeneity of mass, are results apparently beyond the production of any known operations in nature; and if they do find their analogues in any degree, we must look more than we have hitherto done to the chemistry and physical geography of the ocean for a better solution of the problem. It must also be remembered that we are too much in the habit of overlooking the effects of "metamorphism" or internal change in the rock-masses of the solid crust. Subjected as they are to enormous pressure, to a higher and more uniform temperature, to internal chemical and molecular change, to approximation by percolation, and to the incessant transmission of magnetic currents, it may be that new segregations and structural arrangements are continually taking place—and this more rapidly and extensively among rocks

of semi-chemical origin, like limestone, coal, rock-salt, and gypsum, than among those of mere mechanical aggregation. What has been the amount of this metamorphism or internal change during the lapse of ages, we have no direct means of ascertaining, though the universal and unfailing nature of the agencies undoubtedly implies something much more extensive and decided than is usually allowed for. Until all these matters, however, are more familiar to science, geologists must rest contented with merely indicating the line of reasoning that seems to lead to a satisfactory solution of their problems.

244. That such is the real state of this interesting but difficult question, the student may further gather from the annexed opinions of Professor Phillips and Sir Charles Lyell: "The salt and gypsum," says the former, "usually associated in this remarkable system present also their difficulties. Not that it is hard to suppose the waters of the ancient sea to have been so evaporated as to permit first the crystallisation of sulphate of lime, and finally of muriate of soda. But in this case we should expect to find almost uniformly over the whole area regular strata of gypsum below, and regular layers of salt above; while in fact we more commonly find salt in great broad masses rather than beds below, and gypsum in scattered masses above. A general drying of the waters in which the saliferous system was deposited is plainly inconsistent with probability; and we must have recourse to local causes, something analogous, perhaps, to those which influenced the deposit of the primary limestone [namely, developments of subterranean heat, which, directly by change of temperature, or by intermediate chemical agencies, rendered the calcareous matter insoluble over limited areas]. It may be conceivable that the solubility of muriate of soda in water is capable of diminution through the admixture of other substances in the liquid, or through the effects of great pressure, or of pressure and heat combined; it may be maintained that the limited deposits of salt happened in separate lagoons of the sea, exposed to local desiccation, as perhaps in Cheshire. Lyell has still a different and less probable view of the subject. All these explanations assume that the salt was produced directly by *mere* crystallisation, from waters almost perfectly analogous to those of the actual seas; an assumption strongly confirmed by the recent discoveries connected with bromine and iodine [viz., the different ratios of solubility possessed by the hydrobromic and hydriodic salts, compared with that of common salt or chloride of sodium]. Further researches, both chemical and geological, must determine these and other theories; and, in particular, we must be more exactly informed

of the ancient hydrography of the salt districts, which in almost every instance must have been very different from their present topographical features." The following, on the other hand, are the views of Sir Charles Lyell, to which Professor Phillips above alludes, although it is but right to add, that in the last edition of his *Manual* Sir Charles gives the grounds of both theories—volcanic and solar evaporation—without apparently adopting either. "The gypsum and saline matter," he writes, "occasionally interstratified with red clays and sandstones of various ages, primary, secondary, and tertiary, have been thought by some geologists to be of volcanic origin. Submarine and subaerial exhalations often occur in regions of earthquakes and volcanoes far from points of actual eruption, and charged with sulphur, sulphuric salts, and with common salt or muriate of soda. In a word, such 'solfataras' are vents by which all the products, which issue in a state of sublimation from the craters of active volcanoes, obtain a passage from the interior of the earth to the surface. That such gaseous emanations and mineral springs, impregnated with the ingredients before enumerated, and often intensely heated, continue to flow out unaltered in composition and temperature for ages, is well known. But before we can decide on their real instrumentality in producing in the course of ages beds of gypsum, rock-salt, and dolomite, we require to know more respecting the chemical changes actually in progress in seas where volcanic agency is at work." Such are the guarded expressions of Sir Charles with respect to the "volcanic" hypothesis; nor is he more decided as to the "evaporation" process, though at first sight he seems to incline to the former, as affording the readiest and most satisfactory solution of the difficulty.

245. In following out a more detailed investigation of the Triassic system, the student will derive assistance from a perusal of the following authorities:—*Memoirs of the Geological Survey*, vol. ii.; Alberti's *Monograph des Bunter Sandsteins*; Mr Holland's paper in the *Geological Transactions*, together with various contributions on the English Trias in the same publication by Strickland, Buckland, and Murchison; Mr Ormerod in the *Quarterly Journal of Geology*, vol. iv.; Professor Hitchcock in the *Memoirs of the American Academy*, vol. iii., N.S., and his *Ichnology of New England*; Sir W. Jardine's *Ichnology of Annandale*; and Professor Lea's *Fossil Footmarks in the Red Sandstones of Pottsville, Pennsylvania.*

XV.

THE OOLITIC SYSTEM:

EMBRACING—1, THE LIAS; 2, THE OOLITE; AND, 3, THE WEALDEN.

246. WHATEVER doubt may be entertained as to the epoch of some of the triassic strata, there can be none as to the biological relations of the system we are now about to consider. We have passed the boundary, as it were, of the older rocks, and have fully entered upon the upper or younger secondary formations. Or, speaking palæontologically, we have traced the history of systems whose fossils are all of Palæozoic types, and now proceed to interpret the records of those that are unmistakably Mesozoic. The grand types and patterns are still the same—radiate, molluscan, articulate, and vertebrate;—but the modifications of these types are new, and the consequent organisation higher and more complex. We now take farewell of the graptolites, cystideans, trilobites, and eurypterites of the Silurian seas—of the gigantic crustaceans and bone-encased fishes of the old red sandstone—of the sigillaria, stigmaria, lepidodendron, and other endogenous forms of the coal period—of the cup-in-cup, honeycomb, chain, spider-web, and other corals of the Devonian and mountain limestones—of the huge reptile-like fishes that swarmed in the Carboniferous seas—and are introduced to other species and newer forms of vitality. The vegetation that adorns the lands of the Mesozoic period bears a closer resemblance and affinity to the tree-ferns, cycads, zamias, palms, and sub-tropical pines of the present day; and the botanist feels that he can now institute comparisons with some prospect of success, and attempt restorations with greater

confidence and certainty. So also in the animal world: the approximations are becoming closer and closer; the divergence from existing families is less perceptible even to the unscientific observer; and the zoologist now meets with all the great divisions of vertebrate life—fishes, birds, reptiles, and mammals. A marked progress has been made in the great onward evolution of vitality—whole families of lower life have died out, and higher ones have taken their places—and orders only beginning to come into existence in the primeval world are now approaching their culmination, or point of greatest numbers, variety, and development. Besides these gradational advances from lower to higher forms which are common to every geological epoch, we have also some curious external characteristics which must arrest the notice of even the least scientific of geological observers. Thus, in the palæozoic endogens, the ultimate development of the leaf is for the most part stamped in permanent beauty on their tall sculptured stems, whereas in the neozoic exogens it ascends to the more exquisite but evanescent beauties of the flower and fruit. Again, the palæozoic leaf, being endogenous, has a venation wholly parallel; whereas the neozoic leaf adds the reticulated venation of the exogen to that of the endogen. Further, as the floral arrangement of the endogen is governed by *three*, and that of the exogen by *five*, all the palæozoic flowers and fruits are stamped by the normal number *three*, whereas *fives* and *threes* are equally normal in the neozoic flora. So also in the animal kingdom: the corals of the palæozoic cycle had their septa or ray-like partitions arranged in *fours*, while those of the neozoic are arranged in *sixes;* in the palæozoic cephalopods the arms are for the most part void of sucking discs, while those of neozoic seas are, on the other hand, generally furnished with them; in the palæozoic chambered shells the septa or sutural divisions between the chambers are plain and simple, in the neozoic they are, for the most part, of foliated and intricate patterns; the palæozoic crustaceans are more larval-like or abdominal in their segmentation than the neozoic, where head, thorax, and abdomen become distinct and definite; and the palæozoic fishes had all the heterocercal or unequally-lobed tail (which marks the embryonic condition of all fish-life), while in the neozoic orders the heterocerque is subordinated, and the homocerque or equally-lobed and the undivided tails become the general and normal forms. These and other distinctions, upon which the nature of an elementary Text-Book forbids us to enlarge, stamp the Palæozoic as a life-period widely different from that of the Mesozoic, and yet there was no break—no discontinuity in the great evolution of vitality.

As the life of one system runs imperceptibly into that of another, and the two have always some forms in common, so the Palæozoic runs into the Mesozoic, and it is only when viewed as a whole, and at a sufficient distance, that its distinctive characters stand out in bold and peculiar relief. The Triassic system, as already stated, is considered as marking the dawn of this new cycle of being—a cycle whose types attain the meridian of their development during the deposition of the oolitic strata, and die away, as we shall afterwards find, at the close of the cretaceous or chalk system. *In thus attaching high importance to fossils as exponents of the past conditions of the world, lithological and physical distinctions must not be disregarded.* There are facts frequently brought to light, and truths explained by the composition, structure, and stratigraphical relation of rocks, which no profusion of fossils could ever interpret; and here the student is reminded that, however attractive palæontological discoveries *may be, they are only of true geological value when taken in* connection with chemical, mineral, and mechanical characteristics.

247. The system about to be described is more typically developed, and has been more minutely examined, in England than in any other region of the world; and there it consists of three well-marked groups, the Lias, the Oolite, and the Wealden. Indeed, so clearly defined are these groups that they are sometimes treated as independent systems; and were it not for certain fossil as well as lithological resemblances that pervade them, this course would in many respects be preferable. It has also been proposed to regard the lias and oolite as one inseparable *Oolitic* system, and to class the Wealden as one of the sub-groups of the *Cretaceous* era—an arrangement that is supposed to exhibit more clearly the peculiar phases of lower and upper mesozoic life. Such divisions, however, are in a great measure arbitrary, and we require to know more minutely than we do both the palæontology and lithology of the Wealden strata in other countries before any permanent decision can be arrived at. In the mean time the progress of the science will not be retarded by regarding the Lias, Oolite, and Wealden as portions of one great system—the student bearing in mind that several of the lower wealden strata contain species identical with those of the upper oolite, while many of the species in its upper beds are prolonged into the greensands of the cretaceous system.

Lithological Composition.

248. Adopting this view, the *Oolitic System* may be said to comprehend the whole of those peculiar limestones, calcareous sandstones, marls, shales, and clays which lie between the new red sandstone beneath and the chalk formation above. And however similar these strata may be in some features, there is no truth in geology more fully established than this, that where the system is complete, the argillaceous laminated limestone and shales termed the *lias* constitute the lowest group; the yellowish granular limestones, calcareous sandstones, sands and clays, called *oolite*, the middle group; and the greyish laminated clays, with subordinate layers of limestone and flaggy ferruginous sandstones, the *Wealden* or upper group. Taking these groups in descending order, the following synopsis exhibits their subdivisions as typically developed over extensive areas in England:—

WEALDEN.	WEALD CLAY. — Greyish or bluish laminated clays imbedding concretions of ironstone, thin layers of argillaceous limestone, and sandy ferruginous flags.
	HASTINGS SANDS. — Sands and sandstones frequently ferruginous, with partings of clay; beds of clay and sandy shale more or less calcareous, with subordinate beds of limestone.
OOLITE.	PURBECK BEDS.—Estuary limestones alternating with sands and clays (formerly grouped with the Wealden).
	UPPER OOLITE.—Coarse and fine grained oolitic limestones, with layers of calcareous sand and concretions (*Portland stone and Shotover sand*); dark laminated clays, with gypsum and bituminous shale (*Kimmeridge clay*).
	MIDDLE OOLITE. — Coarse-grained, shelly, and coralline oolite, with calcareous sands and grit (*coral-rag*); dark-blue clays, with subordinate clayey limestones and bituminous shale (*Oxford clay*); shelly calcareous grit (*Kelloway rock*), with subjacent blue clays.
	LOWER OOLITE.—Coarse, rubbly, and shelly limestones (*cornbrash*); laminated shelly limestones and grits (*forest marble*); sandy layers and thick-bedded blue clay (*Bradford clay*); thick-bedded oolite, more or less compact and sandy (*Bath or great oolite*); flaggy grits and oolites (*Stonesfield slate*); marls and clays with soft marly limestone (*Fuller's earth*); calcareous freestone, irregularly oolitic, and yellow sand (*inferior oolite*).
LIAS.	UPPER LIAS.—Thick beds of dark bituminous shale; beds of pyritous clay and alum shale; indurated marls or marlstone.
	LOWER LIAS.—Dark laminated limestones and clays; bands of ironstone; layers of jet and lignite; beds of calcareous sandstone.

The Lias.

249. It will be perceived from the preceding synopsis that the Lias or Liassic group occupies the lowest portion of the system, and that it is essentially composed of dark argillaceous limestones, bluish clays, and bituminous and pyritous shales. The name *lias*, which is said to be a provincial corruption of the word *liers* or *layers*, refers to the thin beds in which its limestones usually occur. "The peculiar aspect," says Sir Charles Lyell, "which is most characteristic of the lias in England, France, and Germany, is an alternation of thin beds of blue or grey limestone, with a light-brown weathered surface, separated by dark-coloured argillaceous partings; so that the quarries of this rock, at a distance, assume a striped and ribbon-like appearance." Once seen, this banded appearance of a lias cliff is not easily forgotten; but it must be remembered that the clays generally predominate, and that they contain occasional layers of jet or other coal (*jet* being but a lustrous variety of coal), and bands of ironstone nodules or *septaria*. Most of the shales are bituminous and pyritous, and it is not uncommon, after wet weather, for the Yorkshire cliffs, which are composed of these beds, to ignite spontaneously, and burn for several months. Besides *pyrites* (sulphuret of iron), these shales are impregnated with sulphates of magnesia and soda, with salt (chloride of sodium), and other saline compounds which indicate a marine origin. Indeed, the whole aspects of the lias—its fossils, composition, lamination, and absence of pebbly conglomerates—are those of a tranquil deep-sea deposit; or at all events of an extensive marine area removed from the influences of littoral commotion.

250. As developed in England, the Lias occupies a belt of variable breadth, extending from Lyme Regis in Dorset, northwards by Bath, Gloucester, Leicester, Newark, and Gainsborough, to the Humber, and thence to the east coast of Yorkshire. Taken in Yorkshire, Northampton, and Somerset, the formation (according to Phillips) exhibits in descending order the following details:—

1. *Upper lias clay or shale*, full of belemnites and other fossils, intercalated with or graduating to the sands of the inferior oolite, and in some cases containing nodules and bands of limestone.
2. *Marlstone.*—A suite of calcareous, sandy, and irony beds, very rich in fossils, and much analogous to the lowest beds of the lower oolite formation.
3. *Lower lias clay or shale*, full of fossil remains, interlaminated with bands

and nodules of limestone, especially in the lower part, where a collection of these layers constitutes the lias rock.

4. *Lias rock.*—A suite of laminated limestones, with partings of clay, blue, grey, and white, the former in particular containing gryphites and other shells; the latter usually devoid of organic remains. This rock is sometimes consolidated into a united mass, and sometimes divided into separate portions.

5. *Bone bed,* and blue, black, or purple marls, which cover the new red formation in the south of England, and now regarded as the upper capping of the TRIAS.

The Oolite.

251. The OOLITE, as a group, consists of more frequent alternations, and is more varied in its composition than the lias. It derives its name from the rounded grains which constitute many of its limestones—these grains resembling the roe or egg of a fish (*oon*, an egg, and *lithos*, a stone). *Oolite* is the general term, though many of its limestones are not oolitic; *roestone* is sometimes employed when the grains are very distinct; and *pisolite* or peastone (*pisum*, a pea) when the grains are large and pea-like. The student must not expect, however, to find in the field a uniformity of that roe-like texture so prettily exhibited by hand-specimens in cabinets and museums—the fact being that these are picked portions of a system which shows every gradation of rock from true oolite to calcareous grits, and shelly "brashy" sandstones. He should also remember that this peculiar texture, though prevalent in the oolites of England, is by no means restricted to the formation, but occurs in strata of Carboniferous, Tertiary, and Post-tertiary age, and is strictly the result of chemico-mechanical conditions in the seas of deposit, which may recur during any epoch or in any area. As a group, the Oolite proper may be said to consist of alternations of oolitic limestones, calcareous grits, shelly conglomerates, yellowish sands, and clays less or more calcareous. The peculiar roe-like grains which constitute the oolite texture, consist either entirely of lime, or of an external coating of lime collected round minute particles of sand, shells, coral, &c.; the grits are composed of fragments of shells, coral, and sand; many of the strata have a brecciated aspect, hence known as *ragstones;* and some of the shelly beds, on exposure to the atmosphere, break up into a rubbly sandy soil, whence the provincial *cornbrash* of the English farmer. Like the lias, the oolite is strictly a marine deposit, but its corals, broken shells, and grits point to shallower waters, to exposed beaches and sandbanks, over which waves and tidal currents spent their

forces, and which repeatedly changed level during the deposition of the system.

252. As a deposit of great extent, and taking place under such circumstances, it necessarily exhibits much local diversity of composition. Superimposed on the Lias, it occupies in England a broad parallel belt stretching from Dorset to Yorkshire, and in this area has been more minutely examined than in any other region. Arranging it into Upper, Middle, and Lower series, the following tabulation sufficiently exhibits its stratigraphical details :—

UPPER OOLITE of Purbeck, Portland, Wilts, Bucks, Berks, &c.	*Purbeck Beds.*—Blue clays and laminated limestones, exhibiting, according to Forbes, alternations of fresh-water and estuary conditions of deposit. *Portland Oolite.*—Oolitic and earthy and compact limestones with marine shells, and layers of nodular chert. *Shotover Sand.*—Calcareous sand and concretions. *Kimmeridge Clay.*—Thick blue clay, bituminous, with septaria and marine remains; and, especially in the lower part, bands of sandy concretions.
MIDDLE OOLITE of Oxford, Berkshire, Yorkshire, &c.	*Coral Rag.*—An upper calcareous grit with marine fossils; coralline oolite rich in zoophytes (hence the name coral rag), and a lower calcareous grit, with bands of clay and marine shells. *Oxford Clay.*—Dark blue and greyish clays, with septaria and fossils; subordinate beds of clayey limestone and bands of shale. *Kelloway Rock.*—A calcareous grit (rarely oolitic) very rich in fossils, with a subjacent bed of blue clay.
LOWER OOLITE in Gloucestershire, Oxfordshire, Northamptonshire, &c.	*Cornbrash Limestone.*—A coarse shelly rock of variable and small thickness, but remarkable continuity. *Forest Marble.*—Sand with concretions of sandstone and nodules of fissile arenaceous limestone; coarse shelly oolite, in some places slaty; sandy clay and blue clay of Bradford. *Great Oolite.*—A calcareous and mostly oolitic rock, of variable thickness and changeable nature, the upper beds shelly, the lower sometimes laminated (Stonesfield slate). *Fuller's Earth.*—A series of marls and clays with included beds of soft marly or sandy limestones and shells. *Inferior Oolite.*—A coarse often very shelly rock of limestone, irregularly oolitic, occasionally interlaminated with sand, especially in the lower parts; ferruginous sand with concretionary masses of sandy limestone and shells.

The above presents the general succession of the strata as de-

veloped in the counties referred to; but it must be observed that considerable differences occur even in the area of England, while in Scotland, and on the Continent, the minor series are altogether differently composed. Again, in certain areas, there occur available beds of coal, with their under-clays, and bituminous shales, which give to the formation quite a "carboniferous" aspect, were it not for the fossil plants, which are altogether different, and not to be mistaken, even by an unpractised eye, for those of palæozoic coal-fields. On the whole, the great groups, as developed in Europe, can be readily co-ordinated, and little difficulty is experienced in determining their place in the system. "In the north of France, for example, most of the groups acknowledged by the English geologist may be recognised as the lias, inferior oolite, Bath oolite, forest marble, Oxford clay, coralline oolite, Kimmeridge clay, and even the Portland oolite and Wealden; and the organic remains are either very similar or identical."

The Wealden.

253. The WEALDEN group—so termed from the "Wolds" or "Wealds" of Kent and Sussex, where the deposit prevails—consists chiefly of clays and shales, with subordinate beds of indurated sands, sandstones, and shelly limestones, that indicate an estuary or brackish-water origin. Thin partings of lignite and bituminous shale are not unfrequent among the clayey strata. The group is of limited extent in England and on the continent of Europe, while in other regions its precise equivalents have not yet been detected. As typically developed in Kent and Sussex, the wealden seems to occupy the site of an ancient estuary, which received the clay and mud of some gigantic river, whose waters occasionally bore down the spoils of land plants and land animals, to be entombed along with those of aquatic origin.

254. Separating the Purbeck beds, which were originally classed with the Wealden, the group may be said to consist of two main members—the Weald clay and Hastings sands—which, when analysed, exhibit the following particulars, taken in descending order:—

Weald Clay.—Thick blue clays, having in the upper part septaria of argillaceous ironstone, and in the lower parts beds of the shelly freshwater limestone known as "Sussex marble."

Hastings Sands.—Fawn-coloured sand and friable sandstone (Horsham beds); calciferous sandstones, alternating with friable and conglomerate grits (Tilgate beds); white sand and friable sandstone alter-

nating with clay (Worth sandstone); bluish-grey limestone alternating with blue clay and sandstone shale, and some beds of calciferous sandstone (Ashburnham beds).

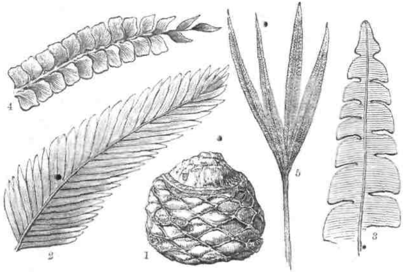
Or more minutely, as has been recently proposed by Mr Drew, of the Government Geological Survey, the subdivisions being taken from localities where the beds are well and typically exposed:—

1. Weald clay.
2. Tunbridge Well sand.
3. Wadhurst clay.
4. Ashdown sand.
5. Hastings sand around Hastings and Battle.

Palæontological Aspects.

255. The organic remains of the system, as already stated, are all *Mesozoic*—that is, belonging to genera and species differing from those found in the older rocks, and differing also, though less in general aspect, from those of the tertiary and present epochs. They are exceedingly numerous and well preserved, and have long and intimately engaged the attention of palæontologists. VEGETABLE REMAINS are frequent in all the groups, and sometimes occur in such profusion as to form seams of lignite, jet, and coal. The Kimmeridge bituminous shale known as "Kim coal," the carbonaceous shales, lignites, and coals of eastern Yorkshire, the coal of Brora in Sutherlandshire, of Richmond in Virginia, and, perhaps, most of the coal-fields of Hindostan and the Indian Archipelago, belong to the oolite section of the system. Some of the marine deposits contain impressions of sea-weeds (*halymenites*); and in those of estuary origin *equisetites*, *lycopodites*, and other lowly forms, are not uncommon. The terrestrial orders seem to indicate a genial, if not a tropical climate—the more characteristic being arborescent ferns, as *cyclopteris*, *pecopteris*, *sphenopteris*, *tæniopteris*, *otopteris*, &c.; monocotyledonous leaves resembling those of the lily, agavè, aloe, and pine-apple, and endogenous stems known as *endogenites*; cycads approaching very nearly the existing cycas and zamia, hence termed *cycadites*, *zamites*, *pterophyllum*, *palæozamia*, *zamiostrobus*, &c.; chara-looking plants distinguished as *naiadites*, *chara*, *sphærococcites* (round berry), &c.; palms (*palmacites*) apparently allied to the pandanus or screw-pine; and coniferous stems and fragments resembling the araucaria, yew, cypress, thuja, &c., and hence known by such names as *araucarites*, *taxites*, *cupressinites*,

abietites, pinites, and *thujites*. One of the most remarkable facts connected with the vegetation of the period is the occurrence of

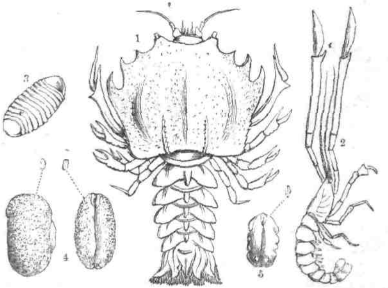


1, Mantellia nidiformis; 2, Pterophyllum comptum; 3, Zamites intermedius; 4, Clyclopteris Beanii; 5 Glossopteris elegans.

dark loam-like strata, locally known as the "dirt-beds" of Portland, and which must have formed the soils on which grew the cycas and other oolitic plants, though now interstratified with limestones, sandstones, and shales. "At the distance of two feet," says Mr Bakewell, "we find an entire change from marine strata to strata once supporting terrestrial plants; and should any doubt arise respecting the original place and position of these plants, there is over the lower dirt-bed a stratum of fresh-water limestone, and upon this a thick dirt-bed, containing not only cycadeæ, but stumps of trees from three to seven feet in height, in an erect position, with their roots extending beneath them. Stems of trees are found prostrate upon the same stratum, some of them from twenty to twenty-five feet in length, and from one to two feet in diameter."

256. With respect to the ANIMAL REMAINS, we have representatives of almost every existing order, with the exception of the higher mammalia,—thus convincing us of the onward and upward progress of creation, but leaving us as much as ever in ignorance of the means by which creative energy accomplished its marvellous designs. Beginning with the lowest forms, we have spongiform organisms, *spongia* and *talpina*; foraminifera in the lias, as *flabellaria, frondicularia*, and *polymorphina*; numerous zoophytes more like the madrepores, star-corals, and brain-corals of existing

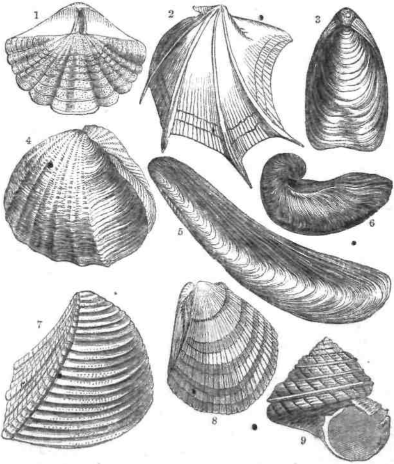
seas than the zoophytes of the silurian and mountain limestones, of which the most abundant are the *isastræa, thamnastræa, montlivaltia,* and *stylina;* crinoids, of which the *apiocrinite* (pear-encrinite) and the *pentacrinite* are the most frequent; star-fishes like the asterias and ophiura, of which the more common are the *astropecten, ophioderma,* and *amphiura;* sea-urchins, as the *cidaris, nucleolites, hemicidaris, diadema,* and *echinus;* worm-like annelids, as *serpula* and *vermicularia;* and crustacea like the minute bivalved *cyprides,* the crayfish-like *eryon* and *megacheirus,* and the lobster-like *glyphea.* Of insects a great



1, Eryon; 2, Megacheirus; 3, Archæoniscus, 4, 5, Cyprides—natural size, and magnified.

profusion has recently been detected in the Stonesfield slate and lias, representing, if we are to accept the imperfect fragments as sufficient evidence, almost every order—coleopterous, neuropterous, orthopterous, dipterous, &c. Of these the beetle-like *buprestium,* the dragonfly-like *libellulium,* the *cercopidium,* and *blattidium,* are perhaps the most abundant. Of the testacea, which occur in vast profusion in all the groups, we can only notice a few of the more characteristic forms, taking them in the usual order. The compound bryozoa occur, but not abundantly, in the lias and lower oolite, and of these the most common are perhaps the *ceriopora, diastopora,* and *cricopora,* so named from their external arrangements; the brachiopods are represented (and of course only in the marine strata of the lias and oolite) by many species of *terebratula, rhynconella, spirifera,* and *discina;* the

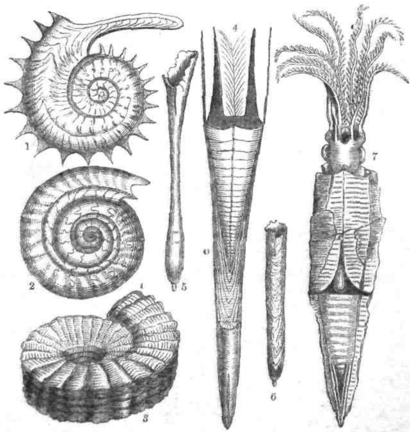
monomyaria in the same way by *pecten*, *ostrea*, *gervillia*, *avicula*, and *gryphæa*; the dimyarian bivalves by *trigonia*, *pholas*, *modiola*, *cardium*, *arca*, *pholadomya*, and many others; no ptero-



1, Spirifer; 2, Avicula; 3, Terebratula; 4, Pholadomya; 5, Modiola; 6, Gryphæa; 7, Trigonia; 8, Plagiostoma; 9, Pleurotomaria.

pods are known, but the gasteropods are abundantly developed, particularly in the lias and lower oolite, and of these *pleurotomaria*, *trochus*, *nerinæa*, *patella*, *cerithium*, and *alaria*, may be noticed as yielding the greatest number of species. So characteristic indeed are some of these testacea of certain members of the formation, that the lias is sometimes termed the "gryphite limestone," and for a similar reason one of the Jura oolites is termed by Continental geologists "calcaire à nerinées." The most remarkable mollusca of the period, however, were undoubtedly the

cephalapodous, which seem to have attained their meridian, both in diversity of form and numerical amount of species, during the deposition of the lias and oolite. Of these the *ammonite* (so called from its resemblance to the curved horn on the head of Jupiter Ammon) appears to have thronged the waters in many hundreds of species, and of all sizes, from shells of half an inch to shells of three feet in diameter. The *nautilus*, *ancyloceras* (crooked horn), and a few others, were the congeners of the ammonites, though not appearing in anything like the same profusion. Gigantic cuttle-fishes were also contemporaries of the ammonite and nautilus, and have left evidences of their existence in the *belemnites* (*belemnos*, a dart), which were the internal bones of these marvel-

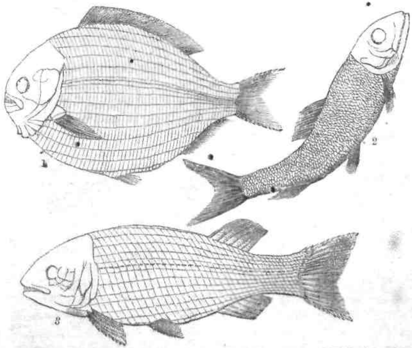


1, Ammonites Jason; 2, A. communis; 3, A. Bucklandi, 4, Belemnites Puzosianus; 5, 6, Belemnites; 7, Belemnoteuthis.

lous mollusca. Indeed, so varied and numerous are the specific forms of these ammonites (there being upwards of 120 species found in the lias alone) that it would require almost a volume to

describe the peculiarities of their configuration and supposed functional arrangements. The student, however, by the aid of a few entire specimens, which can be readily procured, and a section of the existing nautilus, will soon learn enough for the purposes of generalisation; the minuter details must be left to the professed palæontologist and zoologist. (See Recapitulation.)

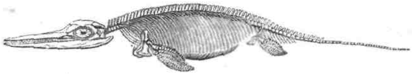
257. Of the higher or vertebrated forms of life, we have many examples of placoid and ganoid fishes, and of sauroid reptiles, a single specimen or so of bird (*palæornis*), and three or four species of marsupial mammals. The placoids are represented by such forms as *hybodus*, *acrodus*, *strophodus* (turn-tooth), *ganodus* (enamel tooth), and *asteracanthus* (star-spine)—the teeth and spines of shark-like genera resembling the cestracion of Australian seas; and the ganoids by teeth, scales, and other ichthyolites which have received the provisional names of *pycnodus* (strong-tooth), *æchmodus* (point-tooth), *eugnathus* (great-jaw), *pachycormus* (thick-trunk), *leptolepis* (slender-scale), *lepidotus*, *dapedius*, and



1, Dapedius tetragonolepis; 2, Leptolepis sprattiformis; 3, Lepidotus Valdensis.

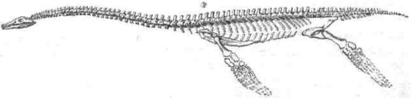
the like. Of the reptiles there are several forms of tortoise and turtle; some seem to be allied to the crocodiles, gavials, monitors, and iguanas of tropical climates, while others are so peculiar in their structure and apparent modes of existence that zoology

seeks in vain for any analogy in existing nature. Under such circumstances palæontologists have been compelled to adopt a new arrangement of these reptilia, subdividing them into dinosauria (terrible saurians), crocodilia, lacertilia, enaliosauria (sea-saurians), chelonida, and pterodactylida (wing-fingered). Under the first division we have such gigantic forms as the *hylæosaurus* (forest or weald saurian), the *megalosaurus* (great saurian), and the *iguanodon*, so termed from the almost perfect identity of the teeth and skeleton of a huge Wealden form with those of the living iguana of South America. Under the second we have the *cetiosaurus* (whale-like saurian), *crocodilus*, *teleosaurus* (perfect saurian), and many others. The lacertilia exhibit a few doubtful forms, as *lacerta* and *nothetes*, while the sea-saurians are represented by numerous species of the well-known *ichthyosaurus* (fish-like



Ichthyosaurus communis.

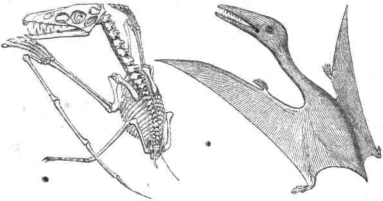
saurian), whose skeletons have been found almost perfect to the smallest vertebra, rib, and joint of the swimming paddle—even with the undigested remains of the cuttlefishes on which the creatures had preyed; the *plesiosaurus* (so called from its closer resemblance to the true saurians), distinguished by its enor-



Plesiosaurus dolichodeirus.

mous length of neck, smaller head, and shorter body and tail; the *pliosaurus*, an intermediate form, as it were, between the two former; besides numerous detached bones, coprolites, portions of dermal integument, and the like, which may belong to these, and it may be to other unknown species. Of the turtle family we may mention the *chelonè*, *platemys* and *pleurosternon*, which, with several other genera, occur throughout the system, though more abundantly in the lias and wealden, while under the last division we have only the curious *pterodactylus* (*pteron*, a wing, and *dactylus*, a finger), of

which there are several species, all furnished with membraneous wing-like appendages, something like those of bats, and apparently for the purpose of enabling the animal to lead an aërial

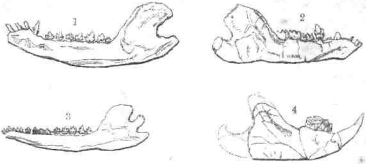


Pterodactylus brevirostris.

as well as terrestrial existence. Of these wonderful reptiles, which seem to have thronged the shallow seas and bays and lagoons of the period, our space will not permit further mention; but so marked and marvellous a feature of the system do they form that the oolitic epoch has been not inappropriately termed "the age of reptiles"—and so abundant and well preserved are their remains that almost perfect specimens are to be found in every public museum of any pretensions. (See Recapitulation.)

258. Of warm-blooded mammals we have evidence in certain jaw-bones, teeth, and detached bones, found in the flaggy limestones of Stonesfield, and in the middle and upper beds of Purbeck. So far as the imperfect fragments will permit of a decision, Professor Owen, Mr Waterhouse, Dr Falconer, and other comparative anatomists, are inclined to regard them as the remains of small insectivorous marsupials, and this opinion seems now acquiesced in by the generality of palæontologists. Respecting the habits, size, and generic affinities of these marsupials, satisfactory evidence is still greatly needed; but in the mean time the student may accept the fact of the existence of warm-blooded terrestrial mammals allied to the smaller pouched quadrupeds of Australia during the oolitic epoch, and regard as provisional genera the *thylacotherium* (*thylakos*, a pouch), the *amphitherium* (*amphi*, doubtful), the *phascolotherium* (*phaskolos*, a pouch), the *spalacotherium* (*spalax*, a mole), and the *stereognathus* (solid-jaw), which appear in the published lists of its fauna. More recently, and in particular during the summer of 1857, numerous specimens of teeth and jaws and detached bones have been discovered by Mr

Beckles in the middle Purbecks of Dorsetshire—some of them insectivorous, others herbivorous, and all, with one or two ex-



Oolitic Mammals, natural size—1, Lower Jaw and Teeth of Phascolotherium; 2, of Triconodon; 3, of Amphitherium; 4, of Plagiaulax.

ceptions, belonging to small marsupial quadrupeds. The discovery, therefore, of the mole-rat-like spalacotherium in 1854, and of the hoofed hog-like stereognathus during the same year, have now been followed by that of the *triconodon* (three-coned tooth), the *plagiaulacodon* or *plagiaulax* (oblique-grooved tooth), and others—thus again correcting the hasty generalisations of limited observation, and pointing the warning finger to those who would attempt to dogmatise on the imperfect data which Geology has yet at its command.

259. In the preceding paragraphs we have indicated only the general palæontology of the epoch—that is, pointed out the leading organisms which occur throughout the lias, oolite, and wealden, as constituting one great stratified system. The student must remember, however, that each group is characterised by its own peculiar fossils, and that while a general facies, or type, runs throughout the whole, there are species and even genera that never pass the boundaries of the lias, while others are restricted to the oolite, or to the wealden. Thus, as might be anticipated, the coralline zoophytes and echinoderms are found almost exclusively in the lower and middle oolite; the great mass of the insects have as yet been detected in the wealden; no marine bivalves or univalves need be looked for in the estuary strata of the weald; while hitherto the ichthyosaurus and plesiosaurus have been yielded only by the strata of the lias and upper oolite. Looking again at specific distinctions, a little practice in the field, or study of a well-arranged collection, will enable the observer to discriminate, for example, between the ammonites of the lias and those of the Oxford clay; between the terebratulæ of the lias and those of the lower oolite; or even between the trigoniæ of the lower

and upper oolites. Each of these groups and series represents, in fact, a long period of time during which the vital manifestations of creation were subjected to the influences of gradually-varying physical conditions—each varying phase of condition being characterised by its own peculiar species; and this altogether apart from the local areas in which the several strata or series of strata were deposited. Thus, the deep-sea beds of the lias may be expected *a priori* to contain genera differing from those of the shallower coral-reefs of the oolite; while the shells of some land-locked lagoon of the weald will naturally differ from those that lived in the brackish waters of its wider and more exposed estuary. It is for reasons of this kind—reasons both chronological and geographical—that the fossils of the lias are often specifically distinct from those of the oolite, and those of the oolite from those of the wealden,—though throughout the whole there is a certain facies of resemblance that unites them into one great *Middle* or *Mesozoic Life-Period.*

Physical and Geographical Aspects.

260. Throughout the whole of the oolitic system in England, the area is marked by faults and axial lines of elevation, rather than by decided outbursts of trap or intersecting dykes of greenstone. There appear to be no contemporaneous effusions of igneous matter, and on the whole, the strata retain much of their original sedimentary flatness. "The parallelism of beds over large regions," says Phillips, "the repetitions of similar rocks at frequent intervals, and the gradual change of the species of organic remains through the whole series, appear to indicate that the long period when the oolitic system was deposited, was one in which the ordinary operations of nature were uninterrupted by paroxysms of igneous violence. On viewing the whole series of these strata, and considering the manner in which their outcrops follow one another, it appears that only a very few instances can be pointed out where any beds of the oolitic system are really unconformed to others of the same system below them." In the north and west of Scotland, however, the detached patches of lias and oolite are upheaved by granitic compounds; and in France and in Germany the ranges of the Jura and Erzgebirge, with their subordinate spurs of elevation and dislocation, belong to the period. In Virginia the Richmond oolites occur in a depression of the granitic rocks; and in India the Cutch oolites have been subjected to repeated igneous commotion of ancient as well as of recent date.

261. The physical features of oolitic districts, more especially

as known to us in England, are by no means unpleasing—the alternations of limestones and clays on a grand scale producing a succession of rounded ridges and sloping valleys. These undulations are very marked in some districts of England and France, where the limestones, which have resisted denudation, compose the ridges, and the softer clays and shales the valleys. Comparatively speaking, none of these ridges are of great height, the lower oolite rising in the midland counties of England to 800 or 900 feet, and the middle oolite to little more than 400—and, being on a limestone subsoil, are dry and fertile, and present a marked contrast to the stiff soils of the "coombs" and "wolds" occupied by the lias and wealden clays. It must not be imagined, however, because oolitic districts want the boldness and abruptness of primary regions, that they are altogether tame and devoid of beauty; on the contrary, the steeper escarpments of the oolitic ridges, rising in terrace-like fashion above the green vales below, and occasionally furrowed by streams into wooded dells and gorges, confer on certain districts of England (Bath, the Cotteswolds, &c.) every charm of rural landscape.

262. The areas overspread by the oolitic system are rather limited and partial. It is most typically developed in England, where the lias and oolite proper occupy a broad stripe stretching from Yorkshire to Dorset; detached patches occur in the north and west of Scotland (Brora, Skye, &c.); and portions of the system are spread over considerable areas in Germany, Switzerland, and France, where the oolitic members are generally known as the "Jurassic system." It is found skirting the Apennines in Italy; flanking the southern Himalayas, spreading, with workable seams of coal, over large areas in Middle Hindostan; occurring also with seams of coal in Borneo and the Indian Archipelago; and recently equivalents with remains of *plesiosauri* have been detected in Middle Island, New Zealand. In America, the well-known coal-field of Richmond in Virginia belongs to this period, as may other areas in the Southern States at present doubtfully referred to the Trias and Chalk formations. Over large areas in Eastern Europe and Northern Asia the formation is altogether unrepresented; and no decided equivalents have yet been examined in Africa or South America. With respect to the Wealden group, its existence in England is restricted to the wolds of Sussex, Surrey, and Kent; it is found on the western coast of France, and equivalent beds have been detected in Hanover and Westphalia. Beyond these limits its existence is yet unknown to geologists.

263. Respecting the conditions of the world during the deposition of the wealden, oolite, and liassic strata, we have already

stated that everything reminds us of a genial, if not of a tropical, climate. "The close approximation of the amphitherium and phascolotherium," says Professor Owen, "to marsupial genera now confined to New South Wales and Van Diemen's Land, leads us to reflect upon the interesting correspondence between other organic remains of the British oolite and other existing forms now confined to the Australian continent and adjoining seas. Here, for example, swims the *cestracion*, which has given the key to the nature of the palates from our oolite, now recognised as the *teeth* of congeneric gigantic forms of cartilaginous fishes. Not only *trigoniæ*, but living *terebratulæ* exist, and the latter abundantly, in the Australian seas, yielding food to the cestracion, as their extinct analogues doubtless did to the allied cartilaginous fishes called *acrodi* and *psammodi*, &c. Araucariæ and cycadeous plants likewise flourish on the Australian continent, where marsupial quadrupeds abound, and thus appear to complete a picture of an ancient condition of the earth's surface, which has been superseded in our hemisphere by other strata, and a higher type of mammalian organisation." Professor Phillips remarks to the same effect—"It is interesting to know that the earliest mammalia of which we have yet any trace were of the marsupial division, now almost characteristic of Australia, the country where yet remain the trigonia, cerithium, isocardia, zamia, tree-fern, and other forms of life so analogous to those of the oolitic periods."

264. "During the oolitic period," continues the latter authority, "the arctic land was covered by plants like those of hot regions, whose vegetable remains have locally generated coal-beds, adorned by coleopterous, neuropterous, and other insects, among which the flying lizard (pterodactylus) spread his filmy wings. The rivers and shores were watched by saurians more or less amphibious (megalosaurus, iguanodon), or tenanted by reptiles which by imaginative man have been thought to be the originals of our gavials and crocodiles, while the sea was full of forms of zoophyta, mollusca, articulosa, and fishes. Undoubtedly the general impression, gathered from a survey of all those monuments of earlier creations, is, that they lived in a warm climate; and we might wonder that the result of all inquiry has shown no trace of man or his works, did we not clearly perceive the oolitic fossils to be all very distinct from existing types, and combined in such different proportions, as to prove that circumstances then prevailed on the globe materially different from what we now see, and probably incompatible with the existence of those plants and animals which belong to the creation whereof man is the appointed head."

Industrial Products.

265. Industrially the system is by no means void of importance. Some of the oolitic strata, like those of Bath and Portland, form excellent building-stone, and are extensively used for that purpose in the south of England. The well-know Caen stone is also a member of the same group; while paving-stones and roofing-flags are obtained from some of its fissile sandstones (Stonesfield, Collyweston, &c.), and also from those of the Wealden at Purbeck, and other parts of Sussex. Both the lias and oolite limestones are largely quarried for mortar; and the former, which generally contain from 80 to 90 per cent of carbonate, with clay and oxide of iron, when well prepared, furnish an excellent hydraulic cement. Marbles of various quality are procured from the lower beds of the Weald, in Sussex ("Sussex or Petworth marble"), and in Purbeck ("Purbeck marble"); and also from some of the coralline and shelly oolites, as at Whichwood Forest, in Oxfordshire, whence the term "Forest marble." The finer kinds of lias receive a polish, and have been tried with indifferent success for lithographic blocks—the chief supply of which has long been obtained from the oolitic beds of Solenhofen and Dichstadt, in the centre of the German Jura. The pyritic clays and shales of the Yorkshire lias yield on proper treatment sulphate of alumina (the *alum* of commerce), which at one time was also obtained from the Kimmeridge clay; and during the sulphur monopoly of Sicily, several patents were taken for the extraction of sulphur from the same pyritic (sulphuret of iron) liassic strata. Fuller's earth—which is essentially composed of silica, alumina, and about 24 per cent of water, and like other aluminous marls possesses in a high degree the property of absorbing grease—is a product of the upper oolite, and was at one time extensively used in the cleansing and scouring of woollens. Iron was at one time extracted from the nodules and pisiform iron-sands of the Wealden; ironstone of workable quality occurs in the oolites of Yorkshire, and has long been gathered along the shores of the same county from the waste of the lias cliffs. The great ironstone treasury of the system, however, is the "Lias band" of Yorkshire. "Within the last few years," says Phillips, "this band, often 16 feet thick, and of good quality, has been worked to great advantage at Eston, and other points in Cleveland [where, we may add, it is creating quite a revolution in the appearance and industry of the country], as well as at Gromont Bridge, in Eskdale. The area under which this bed *may* be worked measures some hundreds of square miles,

with an average produce of 20,000 to 50,000 tons per acre. It dies out southwards, and vanishes about Thirsk; but there other ironstones acquire value in the oolitic series above." A bituminous shale, or brown shaly coal, with a specific gravity of about 1.32, and burning with a dull smoky flame, occurs in the Kimmeridge clay, under the name of "Kim coal," and has been worked for the extraction of paraffine, &c.; and jet (which is simply altered coniferous wood) is found both in the wealden and lias. Seams of coal, which are sometimes workable, occur in the system, as in the oolite at Gristhorp, in Yorkshire; at Brora, in Sutherlandshire; at several places in the German wealdens, from 2 to 3 feet thick; in the East India oolites: and notably at Richmond, in Virginia, where a valuable field extends about 26 miles in length, and from 4 to 12 in breadth.

266. To divest the student's mind of the common but mistaken notion (fostered by grandiloquent generalisers on the designs of Providence, who never shouldered a geological bag, or wielded a hammer), that coal is only a product of the carboniferous era, we transcribe the following from Sir Charles Lyell's description of the Richmond coal-field: "These Virginian coal-measures are composed of grits, sandstones, and shales, exactly resembling those of older or primary date in America and Europe, and they rival, or even surpass, the latter in the richness and thickness of the coal-seams. One of these—the main seam—is in some places from 30 to 40 feet thick, composed of pure bituminous coal. On descending a shaft, 800 feet deep, in the Blackheath mines in Chesterfield County, I found myself in a chamber more than 40 feet high, caused by the removal of the coal. Timber props, of great strength, supported the roof; but they were seen to bend under the incumbent weights. The coal is like the finest kinds shipped at Newcastle, and when analysed yields the same proportions of carbon and hydrogen—a fact worthy of notice when we consider that this fuel has been derived from an assemblage of plants very distinct specifically, and in part generically, from those which have contributed to the formation of the ancient or palæozoic coal." In fact, as before mentioned, coal (though the great available coal-fields of Europe and America belong to the Carboniferous or Palæozoic period) is the product of no epoch in particular, or rather is a product of all epochs—the *anthracites* of Siluria, the *coals* of the Carboniferous and Oolitic systems, the *lignites* of the Chalk and Tertiary, and the *peat* of the current era, being, though differing in quality, merely the representatives of one and the same material.

NOTE, RECAPITULATORY AND EXPLANATORY.

267. The Oolitic system, as typically developed in England, is separable into three well-marked groups—the Lias, the Ooolite, and Wealden. So distinct in many respects are these groups, that they are sometimes treated as independent systems, and in all likelihood the progress of discovery will compel either this arrangement, or the grouping of the lias and oolite into one inseparable system, and the association of the Wealden with the lower greensands of the cretaceous era. As it is, we have adopted the usual grouping, which may be briefly tabulated as follows:—

WEALDEN.	Weald clays.	
	Hastings sands.	
OOLITIC or JURASSIC.	Purbeck beds,	*Upper.*
	Portland stone and Shotover sand,	
	Kimmeridge clay,	
	Coral rag,	*Middle.*
	Oxford clay and Kelloway rock ;	
	Cornbrash and forest marble,	*Lower.*
	Bath or great oolite,	
	Stonesfield slate,	
	Fuller's earth and clay,	
	Inferior oolite,	
LIASSIC.	Upper lias clay or shale.	
	Marlstone.	
	Lower lias clay or shale.	
	Lias rock.	

From the preceding synopsis, it will be seen that the system is mainly composed of argillaceous limestones, limestones of oolitic texture, calcareous sandstones, shelly and coralline grits, clays, pyritous shales, and ironstone, with seams of coal, jet, and lignite. All the members are well developed in England; it is chiefly the lias and oolite that are found in France, Switzerland, and Germany; patches of the lias and oolite occur in Scotland; the oolite alone in Hindustan and North America; and beds of Wealden epoch have been detected in Hanover and Westphalia. As deposits, the lias and oolite are eminently marine, though occasionally exhibiting evidence of alternate elevation and depression; while the Wealden and Purbeck beds display frequent alternations of marine with fresh-water or estuary conditions.

268. On the whole, it is not difficult to imagine the conditions under which the entire suite of strata was deposited—seas, shores, and estuaries of varying and variable depth, were the great receptacles of the heterogeneous sediments which compose the system—deep and tranquil waters for the finely laminated lias,

exposed shores and shallower waters for the shelly grits and coralline conglomerates of the oolite, and vast muddy estuaries for the clays and shales of the wealden; while over the whole areas there were repeated elevations and depressions of sea-bottom as well as of terrestrial surface (the "dirt-bed," &c.). Such were evidently the conditions of formation in general terms; but at the same time, over limited areas of the lias there must have been sudden influxes of turbid and mineral-impregnated waters, to cause the sudden death of the saurians and other marine creatures which crowd certain spaces without a single scale or bone being removed from its place—clear and tranquil waters favourable to the long slow growth of the corals of the oolite—and again, frequent oscillations of surface and varying estuary areas to account for the frequent alternations of the marine and fresh-water exuviæ that occur in the Purbeck and Wealden strata. The prevalence of the oolitic texture in so many of the strata, presents also some difficulties of formation. It is true that many of the so-called oolites are merely calcareous grits,—some composed of comminuted shells and corals, and others of sandy particles coated with lime. But the true oolites, or roestones, seem to be more of chemical than of mechanical origin, and point to conditions analogous to those which favour the formation of the calcareous pisolites of Carlsbad and other mineral waters.

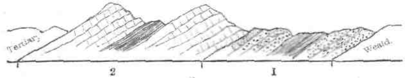
269. Commenting on the curious alternations of muddy shales and limestones that compose the oolitic system, Sir Charles Lyell remarks: "In order to account for such a succession of events, we may imagine, first, the bed of the ocean to be the receptacle for ages of fine argillaceous sediment, brought by oceanic currents, which may have communicated with rivers, or with part of the sea near a wasting coast. This mud ceases at length to be conveyed to the same region, either because the land which had previously suffered denudation is suppressed and submerged, or because the current is deflected in another direction by the altered shape of the bed of the ocean and neighbouring dry land. By such changes the water becomes once more clear and fit for the growth of stony zoophytes. Calcareous sand is then formed from *comminuted shells and coral, or in some cases* arenaceous matter replaces the clay; because it commonly happens that the finer sediment, being first drifted farthest from coasts, is subsequently overspread by coarse sand, after the sea has grown shallower, or when the land, increasing in extent, whether by upheaval or by sediment filling up parts of the sea, has approached nearer to the spots first occupied by fine mud. In order to account for another great formation, like the Oxford clay, again covering one of coral

limestone, we must suppose a sinking down like that which is now taking place in some existing regions of coral between Australia and South America. The occurrence of subsidences, on so vast a scale, may have caused the bed of the ocean, and the adjoining land, throughout great parts of the European area, to assume a shape favourable to the deposition of another set of clayey strata; and this change may have been succeeded by a series of events analogous to that already explained, and these again by a third series in similar order. Both the ascending and descending movements may have been extremely slow, like those now going on in the Pacific; and the growth of every stratum of coral, a few feet of thickness, may have required centuries for its completion, during which certain species of organic beings disappeared from the earth, and others were introduced in their place; so that in each set of strata, from the Lias to the Upper Oolite, some peculiar and characteristic fossils were imbedded."

270. With the exception of the higher mammalia, almost every existing order is represented in the fauna of the oolite, but the forms are all Mesozoic, and died out at the close of the chalk era. The vegetation of the system is also extremely varied, but the highest orders appear to be coniferous, and as yet no example of a true exogenous timber tree has been detected. Of its numerous fossils the most characteristic are the *cycadaceæ*, of which the stems, fruits, and leaves are found in abundance; the shells of the *gryphæa*, so peculiarly plentiful in the lias; the *ammonites* and *belemnites* of innumerable species; the *insects* of the lias and weald; the *pterodactyle*, or flying-lizard; the fresh-water and marine *turtles*; and, above all, the *ichthyosaurus*, *plesiosaurus*, and other sauroid reptiles, whose marvellous forms and variety have suggested for the oolite the not inappropriate title of "the age of reptiles." Still higher in the scale of being than these are the warm-blooded marsupial mammals, *amphitherium*, *phascolotherium*, *spalacotherium*, *stereognathus*, *triconodon*, and *plagiaulax*—the earliest of their kind yet detected in the crust of the earth.

271. The system, as developed in England, has received a vast amount of attention, both in its stratigraphical and palæontological relations. To mention all that has been written by local observers since the time of William Smith, would be to catalogue a large proportion of the papers both in the *Transactions* and *Journal of the Geological Society*. We can only refer the student to the more important contributions of Conybeare, Fitton, Webster, Weston, Buckland, De La Beche, Scrope, Mantell, Murchison, Sedgwick, Lonsdale, Strickland, and others; to the

Reports of the British Association for the papers of Morris, Forbes, Brodie, &c.; and also to the *Memoirs and Decades of the Geological Survey*. Very valuable information will also be obtained from Phillips's *Manual of Geology*, chap. x.; from the *Geology of Yorkshire*, by the same author; from Conybeare's *Geology of England*; Brodie's *Memoir on Fossil Insects*; Baron de Zigno's *Fossil Flora of the Oolitic Formation*; Mantell's *Geology of Sussex*, for the Wealden group; and Buckland's *Bridgewater Treatise*, for much that relates to the structure, functions, and habits of the encrinites, cephalopods, and saurians of the period. The papers of Professor Owen on the oolitic mammals appear in the *Geological Journal*; his report on fossil reptiles in the British Association's volume for 1841; his new arrangement of the reptilia in the Association's volume for 1859, and in his *Palæontology*; and in absence of the *Palæontographie*, the leading types of the ammonites, according to the arrangement of Von Buch and D'Orbigny, may be seen at a glance on the Palæontographical Map of the British Islands, published in the *Physical Atlas* of A. K. Johnston. A fair idea of the configuration and enormous dimensions of the saurians of the period may also be obtained by an inspection of the elaborate models in the grounds of the Crystal Palace—due allowance being made for such details as more perfect specimens will enable the modeller hereafter to correct or supply.



XVI.

THE CHALK OR CRETACEOUS SYSTEM:

COMPRISING—1, THE GREENSAND; AND, 2, THE CHALK GROUPS.

272. IMMEDIATELY above the fresh-water beds of the wealden in the south of England occurs a set of well-defined marine sands, dark marl-clays, and thick beds of *chalk*—a white earthy-looking limestone, with which every one in Britain must be less or more familiar. These strata, which seldom exceed in the aggregate 1000 or 1500 feet in thickness, constitute the *Cretaceous system*—chalk (*creta*) being the most prominent and remarkable feature in the formation. Though neither of great thickness nor widely developed as to area, the Chalk is in many respects one of the most remarkable systems in the stratified crust, and has consequently long attracted the research of geologists. Mineralogically, indeed, it forms a most distinctive stage among the sedimentary rocks; and in general the observer has as little difficulty in determining its limits by lithological aids alone, as he has in discriminating the coal-measures, the mountain limestone, or any other boldly-marked formation. As the uppermost member of the younger secondaries, it closes the record of Mesozoic life; and of the innumerable species which composed the flora and fauna of the secondary epochs, comparatively few have as yet been detected in the Tertiary strata of Europe. It has been customary for certain geologists, generalising from limited tracts in Europe, to draw a bold line of demarcation between the chalk and tertiary—so bold that not a single species was regarded as passing

from the one epoch to the other. This, like many of the earlier conclusions of the science, is altogether erroneous; and now, even in Europe, to say nothing of America, abundant passage-beds have been detected, showing in this instance, as in every other, that abrupt transitions are at the most merely local and limited phenomena. The submergence of old lands, and the elevation of the sea-bed into new islands and continents, is a slow and gradual process: it is never cataclysmal save over the most partial and isolated tracts; and only in such tracts is there a chance of any genus or species being suddenly extinguished.

Lithological Composition.

273. Lithologically, the Cretaceous system in Britain is composed of calcareous, argillaceous, and arenaceous rocks—the former predominating in the upper, and the two latter in the lower portion of the system. The calcareous members are generally known as "chalk" and "chalk marls,"—the former being applied to the purer beds, and the latter to those that are more earthy and clayey; the argillaceous strata, which are for the most part stiff blue marly clays, are known by the provincial term "gault" or "golt;" and the sandy beds, being frequently coloured green by the presence of chloritic matter, are distinguished as "greensands." The nodular masses of "flint" that occur in the chalk consist almost of pure silex, more or less coloured by iron; and the impure calcareo-siliceous nodules and concretions are spoken of as "chert." The system, as occurring in the south of England, is usually grouped as follows:—

CHALK.	UPPER CHALK.—Generally soft white chalk, containing numerous flint and chert nodules more or less arranged in layers. LOWER CHALK.—Harder and less white than the upper, and generally with fewer flints. (Reddish in the north of England, and with abundance of flints.) CHALK MARL.—A greyish earthy or yellowish marly chalk, sometimes indurated.
GREENSAND.	UPPER GREENSAND.—Beds of siliceous sand, occasionally indurated to chalky or cherty sandstone (the "firestone" of Surrey), of a green or greyish white, with nodules of chert. GAULT.—A provincial name for a bluish tenacious clay, sometimes marly, with indurated argillaceous concretions and layers of greensand. LOWER GREENSAND.—Beds of green or ferruginous sands, with layers of chert and indurated sandstones, local beds of gault, rocks of chalky or cherty limestone (Kentish rag), and fuller's earth.

274. The preceding synopsis affords a sufficient outline of the composition and succession of the chalk strata. Of course, considerable local differences occur, and it is sometimes difficult to determine the equivalents of the beds as typically developed in Kent and adjoining counties. Thus, the lower chalk of Yorkshire and of Havre in France contains abundant flint nodules; in Devon and Dorset a gritty bed with numerous fossils occurs towards the base of the chalk; in Lincoln and York a stratum of red chalk is thought to represent the gault of the southern counties; and the Kentish ragstone, which is largely quarried near Maidstone, is wholly unrepresented in the Isle of Wight. When we come to co-ordinate the Continental strata, still wider differences prevail; and in North America the rocks which are charged with cretaceous fossils are often mere sands and clays, sometimes even shingly, and only in certain districts associated with thin beds of yellow coralline and siliceous limestones. Co-ordinating D'Orbigny's topographical subdivisions of the French cretaceous series with those of England, we have something like the following equivalents:—

Danien, . .	Maestricht beds.	English series.
Senonien, . .	White chalk and chalk marl.	
Turonien, . .	Part of the chalk marl.	
Cenomanien, . .	Upper greensand.	
Albien, . .	Gault.	
Aptien, . .	Upper part of lower greensand.	
Neocomien, . .	Lower part of do. do.	
Neocomien inferieur,	Wealden beds and contemporaneous marine strata.	

The lower greensand is thus sometimes termed by English geologists the "Neocomian group" (*Neocomiensis*, rock of Neufchâtel), this portion of the system being thought to be more typically developed in the neighbourhood of Neufchâtel in Switzerland; but recent facts scarcely support this view, and for all practical purposes the terms Chalk, Gault, and Greensand, are sufficiently distinctive.

275. It was stated in the preceding chapter, that, founding on palæontological data, it had been proposed to combine the lias and oolite into one inseparable system, and to merge the wealden into the cretaceous, grouping it along with the lower greensand as "Lower Cretaceous or Neocomian." Adopting this view, and regarding the soft yellow limestones of Maestricht as a local development still higher than the upper white chalk of England, we would have the following tabulation, which is that now adopted by Sir Charles Lyell and other geologists:—

UPPER CRETACEOUS.

1. Maestricht beds and Faxoe limestones.
2. White chalk, with flints.
3. Chalk marl, or grey chalk slightly argillaceous.
4. Upper greensand, occasionally with beds of chert, and with chloritic marl (craie chloritée of French authors) in the upper portion.
5. Gault, including the Blackdown beds.

LOWER CRETACEOUS (*Neocomian*).

1. Lower greensand—Greensand, ironsand, clay, and occasional beds of limestone (Kentish rag).
2. Wealden beds—or Weald clay and Hastings sands.

For the sake of the learner we have followed the usual grouping of the system, but the preceding indicates the new arrangement, which palæontological evidence will in all likelihood ultimately compel the geologist to adopt.

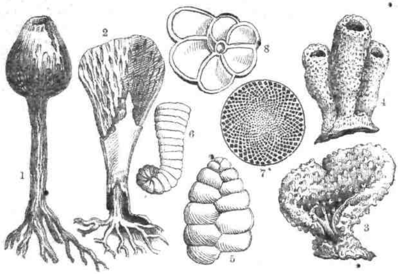
276. The mineral composition of the preceding groups and series is almost sufficiently indicated by their respective terms. The *greensand*, which forms the lower division, is so named from its greenish colour, which it owes to a chloritous silicate of iron. These sands, however, are not uniformly green, but partake of ochraceous and yellow tints; present various degrees of fineness, from compact sands to coarse nodular grits; and not unfrequently imbed cherty bands, nodular sandstones, and irregular deposits of fuller's earth, fossil wood, and ochre. In England the greensand is usually divided into Lower and Upper, because of the stiff blue marly clays (gault) which occur about the middle of the group; but otherwise there is a great lithological similarity throughout its entire thickness, which rarely exceeds 400 or 500 feet. The *gault* or *golt* (a local term) is not of great thickness, not very regular in its occurrence. It is a bluish chalky clay, which effervesces strongly on the application of acids; is interstratified with layers of greensand; and in some localities holds irregular balls of argillaceous ironstone, collected round ammonites and other shells. In some districts the gault assumes a reddish tint, from the iron it contains; but in other respects its composition is very persistent, and it rarely exceeds 80 or 100 feet in thickness. The *Chalk*, which forms the upper group of this system, is too well known to require description. It consists chiefly of carbonate of lime, has an earthy texture, and is so soft as to yield to the nail. Though generally white, it sometimes passes into a dusky grey, or even red colour, as in the north of England; and where it has come into contact with igneous rocks, as in the north of Ireland, it is indurated, and sometimes of a crystalline texture, like that of statuary marble. In England, the chalk group averages from 600 to 800 feet in thickness, and

is usually divided into "lower" and "upper" beds; the former being more compact, of a dusky white varied with green grains, and containing few flints—the latter being a soft white calcareous mass, with chert and pyritic nodules and regular layers of flints. Traces of stratification are scarcely distinguishable in the mass of the chalk, but are clearly evinced by the lines of flints and other nodular concretions. In some of the Continental chalks, carbonate of magnesia prevails to the extent of 8 or 10 per cent, giving to such beds a still more earthy texture; while some of the American equivalents are so siliceous throughout as almost to lose the character of limestones.

Palæontological Characteristics.

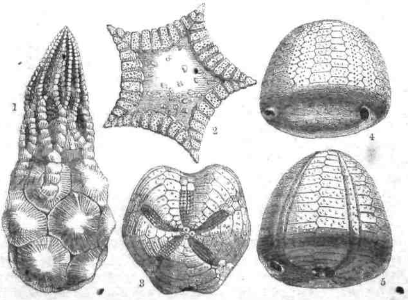
277. The organic remains found in the cretaceous system of Europe are, with a few exceptions, eminently marine, comprising numerous fucoids, sponges, corals, star-fishes, molluscs, crustacea, fishes, and reptiles. As might be expected, FOSSIL PLANTS are comparatively rare, and these for the most part drifted and imperfect fragments. The marine species are apparently allied to the algæ, confervæ, &c., and are termed *chondrites* and *confervites*. The terrestrial types are drifted fragments of filicoid plants (*lonchopteris*); aloe-like leaves (*dracæna*); cycadaceous leaves and fruits (*clathraria, zamiostrobus*); palm-like fruits of unknown affinity (*carpolithes—carpos*, a fruit); and cones and fragments of coniferous wood known by such names as *pinites, abietites*, and *strobilites* (*strobilus*, a fir-cone). In British North America, Vancouver's Island, and other localities, strata regarded as the equivalents of the European Chalk imbed considerable seams of lignite, and even of bituminous coal; thus showing that in certain areas vegetation was more luxuriant, and that the coal-forming operations of nature went forward during the cretaceous as during all the other fossiliferous systems. Of the ANIMAL remains, which are in general beautifully preserved, and to be seen in almost every British collection, we can only notice a few genera under each order or family. Beginning with the amorphozoa or spongiform bodies, which seem to have crowded the waters in certain localities, we have the common and characteristic *ventriculites, cephalites, spongia, scyphia, siphonia*, &c., generally named from the external shape of the mass. Of foraminiferous organisms upwards of thirty genera have been catalogued, as *dentalina, rotalia, textularia, orbitoides*, and *lituola*. Of coralline zoophytes, *parasmilia, trochocyathus, parastræ, aspinopora*, and

the like. Of echinoderms there are many genera in every state



1, Siphonia; 2, Ventriculites; 3, Manon; 4, Scyphia; 5, Textularia; 6, Lituola; 7, Orbitoides; 8, Rotalia.

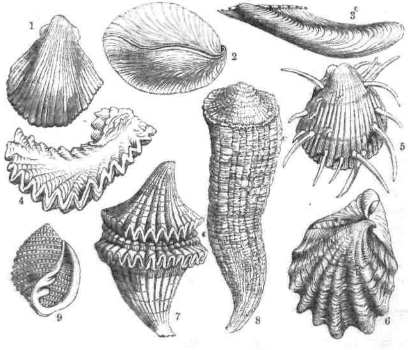
of perfection—sea-urchins, as the *cidaris*, *spatangus*, *galerites*



1, Marsupites; 2, Goniaster; 3, Hemipneustes; 4, Ananchytes; 5, Galerites.

diadema, *ananchytes*, &c.; star-fishes, *goniaster* and *oreaster*;

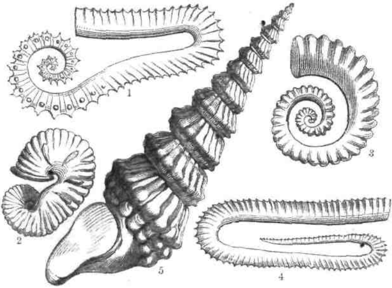
and crinoids, as *marsupites*, *Bourguetocrinus*, and *pentacrinus*. Of annelids, abundant *serpularia* and *vermicularia*; of cirripeds, *scalpellum* and *pollicipes*; and of crustacea, the entomostracous forms, *Bairdia*, *cythere*, and *cytherella*; and the malacostracous lobster-like genera, *myeria*, *pagurus*, and *notopocorystes*. The remains of mollusca are extremely numerous, and in such beautiful preservation that the conchologist can at once assign them a place in his classification. The compound bryozoa appear in great profusion, as *actinopora*, *diastopora*, *pustulopora*, *eschara*, and *retepora*. Of brachiopods, the most abundant are *terebratula*, *rhynconella*, and *crania*; of characteristic monomyaria, we may name *pecten*, *lima*, *ostrea*, and *inoceramus*; and of dimyaria,



1, Pecten; 2, Terebratula; 3, Gervillia; 4, Ostrea; 5, Plagiostoma; 6, Inoceramus: 7, Radiolites; 8, Hippurites; 9, Cinulia.

trigonia, *cardium*, *astarte*, *nucula*, *venus*, *cypricardia*, and the curious massive shells *hippurites*, *diceras*, and *radiolites*. Of the univalves or gasteropods, the *rostellaria*, *cerithium*, *natica*, *cinulia*, *littorina*, and *pleurotomaria*, are typical and characteristic. The cephalopods also appear in considerable profusion, and though the ammonites have evidently passed their meridian, and are now on the decline, we still have many species, with newer and more

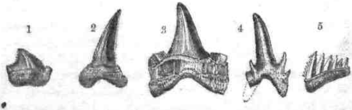
complex forms, of the same great order. Of these the *ammonite*, the *nautilus*, the hook-shaped *hamites* (*hamus*, a hook), the boat-



1. Ancyloceras; 2. Scaphites; 3. Crioceras; 4. Hamites; 5. Turrilites

shaped *scaphites*, the rod-like *baculites* (*baculus*, a staff), the turret-like *turrilites*, the curious horn-shaped genera, *ancyloceras*, *ptychoceras*, &c. (*keras*, a horn), and the dart-like internal belemnites (the "thunderbolts" of the English peasant), are the most frequent and typical.

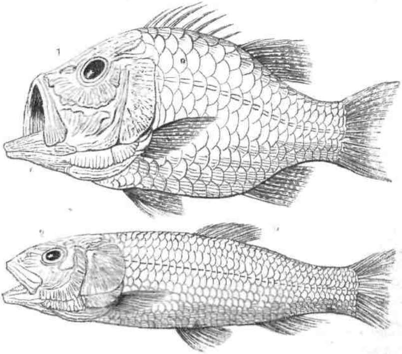
278. The vertebrate remains are those of numerous fishes and reptiles, with occasional indications of birds and mammalia. Of the fishes the majority are still placoid and ganoid; but the ctenoid and cycloid orders, to which almost all existing fishes belong, are here for the first time found in the rocky strata. Of



1. Corax pristodontus; 2. Lamna crassidens; 3. Otodus obliquus; 4. Lamna elegans; 5. Notidanus microdon.

the placoids the teeth and spines are as usual the only remains —the former being most abundantly represented by *ptychodus*

(wrinkle-tooth), *acrodus* (summit-tooth), *corax*, *lamna*, &c.; and the latter by various forms, apparently those of cestracionts. Of the ganoids, *lepidotus*, *gyrodus* (twisted-tooth), *pycnodus* (thick-tooth), and *macropoma*, are the most typical. Of the ctenoid or comb-scaled order, several species of *beryx* (closely allied to the perch) have been detected; and of the cycloideans, the *saurocephalus* and *osmeroides* are those most frequently found in col-



1, Beryx Lewesiensis; 2, Osmeroides Mantelli.—Mantell.

lections. The sauroid reptiles seem identical with or at least closely allied to those of the wealden, and are respresented by *pterodactyles*, *plesiosaurus*, *mososaurus* (from the Meuse), *iguanodon* and *chelonia*. Bird-bones, termed *cimoliornis* (from *kimolia*, white chalk-marl, and *ornis*, a bird), have been described by Professor Owen, who has also surmised that certain mammalian remains are those of quadrumana or monkeys.

Physical and Geographical Features.

279. Regarding the geographical distribution of the chalk, though the several areas may be partial or limited, strata con-

taining the peculiar fossils of the system have been discovered in many countries. As already mentioned, it is finely developed in the south and south-east of England; it is found in the north of Ireland; and from the frequent occurrence of flint nodules in Aberdeenshire, &c., it is supposed to have covered considerable areas in the north of Scotland. It is spread over wide tracts in France and Germany, and occurs in connection with the Alps, Carpathians, and Pyrenees. Chalk fossils have been collected in the south of India; equivalents of the gault and greensands have been investigated in the states of New Jersey, Texas, and Alabama; in the Saskatchewan prairies and Vancouver's Island; and strata apparently of the same age have been noticed in Colombia in South America.

280. Though exhibiting faults and fractures, no igneous rocks have been found associated with the chalk of England. In the north of Ireland the strata are disrupted and overlaid by basalt and other traps, as remarkably displayed at the Giant's Causeway; and in the Pyrenees and Alps the system partakes more or less of all those upheavals, by traps and secondary granites, which are so characteristic of those lofty ranges. Where unbroken by igneous eruptions, the physical aspect of chalk districts is readily distinguished by the rounded outlines of their hills and valleys, as typically exhibited in the "wolds" and "downs" of Kent, Sussex, Surrey, Hants, Wilts, Berks, and other counties in the south of England. These downs are described as "covered with a sweet short herbage, forming excellent sheep-pasture, generally bare of trees, and singularly dry even in the valleys, which for miles wind and receive complicated branches, all descending in a regular slope, yet are frequently left entirely dry; and, what is more singular, contain no channel, and but little other circumstantial proof of the action of water, by which they were certainly excavated." The rains, it is said, are absorbed as fast as they fall upon this dry surface, and sink to considerable depths in the rock, where they are treasured up in reservoirs to the deep wells and the constant springs which issue at lower levels.

281. Combining all the features of the system as developed in Europe—its composition, fossils, and geographical distribution—we are warranted in regarding the chalk as a truly marine deposit, filling up limited seas which were thronged with oceanic life, and which received at intervals the drift of rivers that flowed through countries enjoying an equable and genial temperature. The cycas and zamia are plants which betoken such a climate; and though vegetable drift seldom appears among the chalk strata of Europe in such profusion as to form more than scattered patches of lignite

(as in the lower measures near Rochelle), yet must this circumstance be ascribed more to the unfavourable position of the seas of deposit for the reception of such drift than to the scantiness of vegetation on the dry land. Again, the corals and huge sauroid reptiles would seem to imply almost sub-tropical conditions of *temperature; a circumstance that seems further established by* the presence of remains apparently allied to the monkeys. On the other hand, the recent discovery of a block of granite and another of coal imbedded in the white chalk of the south of England appears to favour the idea of transport by floating ice—a phenomenon that might occur even in genial seas, were these open to the north, and so situated as to become the recipients of icebergs which might occasionally be borne to their waters.

282. Respecting the conditions of the waters in which the chalk, so unlike ordinary limestones, was deposited, and within whose mass flints were subsequently aggregated, geologists are by no means agreed. This much, however, seems certain, that the chalk is a mechanical deposit from waters loaded with calcareous particles, and abounding in minute foraminiferous shells, which constitute a large portion of the mass, and not, as at one time supposed, a precipitate from chemical solution. The abundance of enclosed sponges, corals, shells, and fragments of vegetables also confirms this view, and compels us to seek for the enclosed layers and nodules of flint an origin similar to that of nodules of ironstone and chert in shale. Flints are composed almost entirely of pure silex, with a trace of iron, clay, and lime; they are usually aggregated round some nucleus of sponge, shell, or coral; and there is no difficulty in conceiving the silex to have been originally in solution in the waters of deposit, and subsequently segregated in layers and nodules as we now behold it. (See Recapitulation.)

Industrial Products.

283. Industrially, the chief products of the system are chalk and flint. Chalk, as an almost pure carbonate of lime, is calcined like ordinary limestones, and employed by the bricklayer, plasterer, cement-maker, and farmer; and levigated, it furnishes the well-known "whiting" of the painter. Flint calcined and ground is used in the manufacture of china, porcelain, and flint-glass; and before the invention of percussion-caps was in universal use for gun-flints. In the south of England flints are extensively used as road-material; and the larger nodules are sometimes

taken for the building of walls and fences. Beds of fuller's earth are extensively worked in the greensands, as at Ryegate and Nutfield; and some of the indurated strata, like the "Kentish rag" and Chalk marl of Cambridgeshire, furnish local supplies of building-stone, as well as supplies of road-material. From the Gault and Upper Greensand of Farnham in Surrey are also obtained those phosphatic nodules, now ground down and used as a manure, on account of their containing a large percentage of phosphate of lime. "It is doubtless of animal origin," says Lyell, "and partly coprolitic, probably derived from the excrement of fish."

NOTE, RECAPITULATORY AND EXPLANATORY.

284. The Cretaceous system—so called from the chalk beds which form its most notable feature—is the last or uppermost of the secondary formations. All its types of life are strictly Mesozoic, and of the numerous species found in the Trias, Oolite, and Chalk, not one, it is affirmed by palæontologists, has been detected in tertiary strata. As typically developed in the south of England, the system has been separated into two groups, the *Chalk* and *Greensand*, and these comprise, in descending order, the following members:—

CHALK.	Upper chalk with flints. Lower chalk without flints. Chalk marl.
GREENSAND.	Upper greensand. Gault. Lower greensand.

Adopting the recent views of palæontologists respecting the cretaceous affinities of the Wealden, and adding certain Continental beds which are wanting in England, we have then an Upper and a Lower group, comprising the following subdivisions:—

UPPER CRETACEOUS.	Maestricht beds. Chalk proper. Chalk marl. Upper greensand. Gault.
LOWER CRETACEOUS.	Lower greensand. Weald clay. Hastings sands.

Whichever view is adopted, the entire suite of strata—with the

exception of the fluvio-marine beds of the weald—bear evidence of shallow and widespread seas, and of a climate favourable to the growth of cycads and zamias on land, and of corals, gigantic saurians, and turtles in the waters. Palæontologically, the remains of the chalk and greensand are eminently marine, and comprise numerous species of sponges, corals, star-fishes, sea-urchins, shell-fish, crustacea, fishes, and reptiles. Indications of bird and mammalian remains have also been detected, but these are as yet too scanty and obscure to warrant any definite conclusion.

Formation of Chalk and Flint.

285. Respecting the origin of the rocks which compose the system, some difficulties, both of a physical and chemical nature, present themselves to the geologist. The accumulation of such strata as the gault and greensand can easily be accounted for by the ordinary processes of mechanical sediment; but the chalk, with its great thickness, remarkable homogeneity, and peculiar layers of flint nodules, would seem to indicate a somewhat different process of formation. Even as a limestone, it differs from others so widely in texture and appearance, that several chemical and organic hypotheses have been advanced to account for its origin. "There appears no evidence," says Mr Brande, "of its having been precipitated from chemical solution; but, on the other hand, it bears marks of a mechanical deposit, as if from water loaded with it in a state of fine division. And upon this principle, some gleam of light may perhaps be thrown upon the enigmatical appearance of the flints; for it is found, that if finely-powdered silica be mixed with other earthy bodies, and the whole diffused through water, the grains of silica have, under certain circumstances, a tendency to aggregate into small nodules; and in chalk, some grains of quartz (fragments of siliceous spicula, &c.) are discoverable." There can be little doubt that such has been the original condition of chalk, from whatever source the calcareous particles were derived; for, without the supposition that these particles were diffused through the waters of deposit, it were impossible to account for the imbedding of the fossil organisms, the lines of deposition, and other phenomena connected with it as a stratified formation. But while such has evidently been the origin of the great mass of the chalks, it does not preclude the *chemical* agency of calcareous springs, or the *organic* efforts of lime-secreting zoophytes, or the aggregation of microscopic foraminifera. All other limestones in the crust of the earth point

to a complex formation, in which mechanical, chemical, and organic agencies have been concerned; and it is but reasonable to suppose that chalk is the result of similar forces. Indeed, we have evidence in existing nature of vast accumulations of fine calcareous mud, arising partly from the attrition of coral-reefs, shells, and other marine exuviæ, partly from the secretions and excretions of certain mollusca, echinoderms, and fishes, and partly from the aggregation of minute creatures, as the infusoria, foraminifera, bryozoa, and the like. Even the chalk itself, when carefully pulverised in water, and examined under the microscope, gives similar evidence of its origin; and what appear to the naked eye as mere mineral particles, are in fact well-preserved fossils. In this way Mr Lonsdale obtained thousands of organisms in every pound weight of chalk—some being minute bryozoa and corallines, others entire foraminifera and cytheridæ, and others, again, mere fragments in which the organic texture was still apparent.

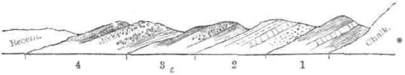
286. The formation of flint within a mass so different in composition as chalk is also in some respects an unsettled problem in geology. It occurs in nodular masses of very irregular (often fantastic) forms and variable magnitude—some of these not exceeding an inch, others more than a yard in circumference. Although thickly distributed in horizontal layers, and occasionally in vertical lines of large nodules or "potstones," the nodules are seldom in contact with each other, each being completely enveloped by the chalk. It is rare, indeed, to find a continuous layer of flint, as we find a layer or band of ironstone, though the nodular or concretionary states of these two materials are precisely similar. Externally, the flints are composed of a white cherty crust; internally, they are of grey or black silex, frequently full of flaws or cracks, and often contain cavities lined with chalcedony and crystallised quartz. When taken from the chalk-pit, they are brittle and full of moisture, but soon dry and assume their well-known hard and refractory qualities. Flints almost without exception enclose remains of sponges, sea-urchins, detached spines, corals, and other marine organisms, the structures of which are often preserved in the most delicate and beautiful manner. In some specimens the organism has undergone subsequent decomposition, and the space it occupied has been either left hollow, or partially filled with some sparry incrustation. From these facts it would seem that flints are aggregations of silex round some organic nucleus, just like the ironstone septaria of the coal-shales, the grains of the oolite, the ironstone nodules of the gault—all of which are aggregations round some organic centre, be it a frag-

ment of plant, a shell, a tooth, coprolite, or other organism This is now the generally received opinion; and when it is re membered that the organisms must have been deposited whei the chalk was in a flocculent and pulpy state, there can be littl difficulty in conceiving how the silex, held in solution by th waters of deposit, would, by chemical affinity, attach itself to th decaying organism. The solubility of silica is a well-known fac in nature; it occurs in most thermal springs—in soils, whence i is elaborated by many growing plants for their structure—in waters, whence sponges and infusoria elaborate their siliceou spiculæ and shells—and all decomposing rocks, like the felspathi granites, greenstones, and tufas, are continually supplying it t the streams, rivers, and ocean. The cause of its abundance in certain cretaceous areas we may never know, but it is altogethe a mistake to suppose that flint is a product peculiar to the Chalk The spongiferous cherts of the Portland and coralline oolites, and the tubipore cherts and flints of the mountain limestone, are *identical in origin, as they are all but identical in composition* Indeed, repeated lines of black flint nodules, aggregated round some coral or sponge, may be traced, in the carboniferous limestones of Linlithgowshire and Derbyshire, as distinctly and continuously, and as purely siliceous, as ever were traced in the chalk-pits of Kent and Surrey.

[Dr Bowerbank, who has paid considerable attention to this subject, and has had unusual facilities for observing the circumstances under which the various forms of flint and chert occur in the chalk formation, is of opinion *that the whole of the numerous strata of nodular and tabular flints are derived from vast quantities of sponges* that existed in the seas of the period. The attraction of the animal matter of the sponges induced, he believes, the deposit of the silex, which in the first instance is always in the form of a thin film surrounding the skeleton of the sponge, and from which successive crops of chalcedonic crystals proceed, until the solidification of the whole is effected. The beds of tabular flint he accounts for on the presumption that the sponges originating the deposit grew on a more consolidated bottom than the tuberous ones, and that they therefore developed themselves laterally instead of perpendicularly, as many species of recent sponges are in the habit of doing, and that, approaching and touching each other, they united, and thus formed extensive and continuous beds, instead of numerous isolated specimens. The occurrence of the shells of bivalves and echinoderms filled with flint or chert, Dr Bowerbank accounts for on the *principle of their having been previously filled with living sponges*, and subsequently fossilised by the deposit in the spongeous tissue of silex held in solution in the water. The loose specimens of fossil sponges contained in the Wiltshire flints he explains on the same principle, but their not adhering to one another he accounts for in accordance with the law, that while sponges of the same species, when brought in contact, readily unite and adhere, those of different species never unite under such circumstances. In fine, Dr Bowerbank applies the same principles to the siliceous deposits of the whole of the geological formations, and expresses his opinion *that the geological office of the Sponges in creation is that of inducing the deposit of*

siliceous matter held in solution in the ocean, as the Corals assist in the consolidation of the calcareous matter.]

287. In consequence of the variety and perfection of its fossils, and the free exposure of its strata in the cliffs, quarries, and railway-cuttings of the south of England, the system has received a vast amount of minute and searching attention. The *Geological Transactions and Journal* teem with papers on one or other of its members, presenting detailed sections, thicknesses, and lists of fossils. Among these, the student may consult the contributions of Fitton, Mantell, Webster, Greenough, Sedgwick, Buckland, Trimmer, and others. Valuable information may also be obtained from Mantell's *Geology of the South-east of England*, Dixon's *Geology of Sussex*, W. Phillips's *Geology of England*, and the *Memoirs of the Geological Survey*. For the elaboration of foreign localities, we are chiefly indebted to D'Archiac, D'Orbigny, De Beaumont, and Hebert, in France; to Professor Dumont in Belgium; to Pusch in Germany; and to H. D. and W. Rogers in America.



XVII.

THE TERTIARY SYSTEM:

EMBRACING—1, THE EOCENE; 2, MIOCENE; 3, PLIOCENE; AND, 4, PLEISTOCENE GROUPS.

288. THE earlier geologists, in dividing the stratified crust into primary, secondary, and tertiary formations, regarded as *tertiary* all that occurs above the Chalk. The term is still retained, but the progress of discovery has rendered it necessary to restrict and modify its meaning. Even yet the limits of the system may be said to be undetermined—some embracing under the term all that lies between the chalk and boulder-drift, others including the drift and every other accumulation in which no trace of man or his works can be detected. Palæontologically speaking, much might be said in favour of both views; but the difficulty of unravelling the relations of many clays, sands, and gravels, makes it safer to adopt, in the mean time, a somewhat provisional arrangement. We shall therefore treat as TERTIARY all that occurs above the chalk till the close of the drift, and as POST-TERTIARY every accumulation which appears to have been formed since that period. In Europe, North America, and indeed over the greater portion of the arctic and temperate regions of the northern hemisphere, the boulder-drift is a bold and clearly-defined formation; and there is little difficulty, therefore, in determining, in these regions, the upper limits of the tertiary system. In the southern hemisphere the drift is not so well defined—a matter of less importance, seeing that the higher latitudes there are chiefly covered by the ocean; but in tropical

and sub-tropical latitudes, where the drift is altogether wanting, there is no lithological boundary to guide us, and we must fall back entirely upon the evidence afforded by organic remains. Taking the formations, however, as they occur in Europe, and more especially as developed in Britain, the arrangement above indicated resolves itself into the following intelligible subdivisions :—

POST-TERTIARY.	RECENT and SUPERFICIAL ACCUMULATIONS occurring above the boulder-drift.	
TERTIARY.	PLEISTOCENE...	Boulder or Glacial drift.
	PLIOCENE.......	Mammaliferous, Red and Coralline crag of Suffolk, &c.
	MIOCENE.......	Faluns of Touraine, Molasse of Switzerland, and part of Vienna Basin.
	EOCENE.........	Strata of London and Paris Basins.

By adopting this view we get rid of certain anomalies connected with the boulder-drift, while there will be no difficulty in removing the pleistocene to the post-tertiary system, should subsequent discoveries render such a transposition necessary.

289. The organic types of the system above tabulated are all *Cainozoic*,—that is, are all less or more allied to, or even identical with, many existing genera. As at the close of the *Palæozoic* cycle, the graptolites, trilobites, eurypterites, pterichthys, coccosteus, megalichthys, stigmaria, sigillaria, lepidodendron, and other forms of ancient life, had passed away ; so, at the close of the *Mesozoic*, the encrinites, ammonites, palæoniscus, labyrinthodon, ichthyosaurus, plesiosaurus, pterodactyle, and other intermediate types, disappeared, and their place was taken by higher and more recent forms. We now find among vegetables evidence of true exogenous timber-trees (that is, trees which increase by *external* layers of growth, like the oak, beech, and elm) ; a large percentage of the corals and shells are identical with those of existing seas ; the reptiles are carapaced turtles and tortoises ; the fishes are chiefly ctenoids and cycloids, with equally-lobed tails ; birds of existing families are by no means rare ; and examples of mammalia of all classes, up to the highest save man, have been detected. Nature, in fact, had made another great move in her onward and upward progress, throwing aside, as it were, the worn-out moulds and patterns of her organic developments, and eliminating others better adapted to the gradually-varying conditions of the inorganic world. Still throughout the whole there runs the same great idea or design ; and thence, though species and genera have changed, the types and functional duties of these types remain, leading us to regard nature as immutable even in

the midst of her incessant mutabilities. As the past merges insensibly into the present, and the present into the future, so *cycle passes into cycle, and system into system, by the finest* gradations; and it is not till the whole is sufficiently removed, and these gradations subordinated, that we perceive the peculiar phases which characterise the successive epochs of geological history. As a whole, therefore, the biological aspects of the tertiary system are sufficiently distinct from any of the systems that have gone before; and though many of its species have long since become extinct, there is clearly a much closer resemblance between them and those of existing nature (Cainozoic) than there is between them and those of Mesozoic or Palæozoic cycles.

290. *As in other systems, so in the tertiary, the fossils of the* older strata differ considerably from those of the newer; and thus the whole might be conveniently grouped into Lower, Middle, and Upper. Palæontologists, however, have chosen a somewhat different nomenclature, and, taking the percentage of fossil shells as their guide, have adopted the scientific divisions already tabulated. Thus *eocene* (*eos*, the dawn, and *kainos*, recent) implies that the strata of this group contain only a small proportion of existing species, which may be regarded as indicating the dawn of existing things; *miocene* (*meion*, less) implies that the proportion of recent shells is less than that of extinct; *pliocene* (*pleion*, more), that the proportion of recent shells is more or greater than that of the extinct; and *pleistocene* (*pleiston*, most), that the shells of this group are mostly those of species inhabiting the present seas. This nomenclature is now in general use by English geologists, though it must be confessed that the progress of fossil discovery has long since rendered the divisions lower, middle, and upper more appropriate, and much less liable to mislead. The terms were first introduced by Sir Charles Lyell in 1833; and it were as well, perhaps, to hear his own explanation and remarks, after a lapse of eight-and-twenty years:—"When engaged," he says, "in 1828, in preparing my work on the Principles of Geology, I conceived the idea of classing the whole series of tertiary strata in four groups, and endeavouring to find characters for each, expressive of their different degrees of affinity to the living fauna. With this view I obtained information respecting the specific identity of many tertiary and recent shells from Italian naturalists, and, among others, from Professors Bonelli, Guidotti, and Costa. Having, in 1829, become acquainted with M. Deshayes of Paris, already well known by his conchological works, I learned from him that he had arrived, by independent researches, and by the study of a large collection

of fossil and recent shells, at very similar views respecting the arrangement of tertiary formations. At my request he drew up, in a tabular form, lists of all the shells known to him to occur both in some tertiary formations and in a living state, for the express purpose of ascertaining the proportional number of fossil species identical with the recent which characterised successive groups; and this table, planned by us in common, was published by me in 1833. The number of tertiary fossil shells examined by M. Deshayes was about 3000, and the recent species with which they had been compared about 5000. The result then arrived at was, that in the lower tertiary strata, or those of London and Paris, there were about three and a half per cent of species identical with recent; in the middle tertiary of the Loire and Gironde, about seventeen per cent; and in the upper tertiary or sub-Apennine beds, from thirty-five to fifty per cent. In formations still more modern, some of which I had particularly studied in Sicily, where they attain a vast thickness and elevation above the sea, the number of species identical, with those now living was believed to be from ninety to ninety-five per cent. For the sake of clearness and brevity, I proposed to give short technical names to these four groups, or the periods to which they respectively belonged. I called the first or oldest of them Eocene, the second Miocene, the third Older Pliocene, and the last or fourth Newer Pliocene. The first of the above terms, Eocene, is derived from *eos*, dawn, and *cainos*, recent, because the fossil shells of this period contain an extremely small proportion of living species, which may be looked upon as indicating the dawn of the existing state of the testaceous fauna, no recent species having been detected in the older or secondary rocks. The term Miocene (*meion*, less) is intended to express a minor proportion of recent species (of testacea); and the term Pliocene (*pleion*, more) a comparative plurality of the same. It may assist the memory of students to remind them that the *mi*ocene contain a *mi*nor proportion, and *pli*ocene a comparative *pl*urality of recent species; and that the greater number of recent species always implies the more modern origin of the strata. It has sometimes been objected to this nomenclature, that certain species of infusoria found in the chalk are still existing, and, on the other hand, the Miocene and Older Pliocene deposits often contain the remains of mammalia, reptiles, and fish, exclusively of extinct species. But the reader must bear in mind that the terms Eocene, Miocene, and Pliocene were originally invented with reference purely to chronological data, and in that sense have always been, and are still, used by me. The distribution of the

fossil species from which the results before mentioned were obtained in 1830 by M. Deshayes was as follows:—

In the formations of the Pliocene, older and newer, .	777
In the Miocene, ...	1021
In the Eocene, ...	1238
	3036

Since the year 1830, the number of new living species obtained from different parts of the globe has been exceedingly great, supplying fresh data for comparison, and enabling the palæontologist to correct many erroneous identifications of fossil and recent forms. New species also have been collected in abundance from tertiary formations of every age, while new discovered groups of strata have filled up gaps in the previously known series. Hence modifications and reforms have been called for in the classification first proposed. The Eocene, Miocene, and Pliocene periods have been made to comprehend certain sets of strata of which the fossils do not always conform strictly in the proportion of recent to extinct species, with the definitions first given by me, or which are implied in the etymology of these terms." In other words, the student must be prepared to receive these terms simply as technical designations for certain series of strata, and to regard them as all but synonymous with Lower, Middle, and Upper Tertiary.

I.—EOCENE, MIOCENE, AND PLIOCENE GROUPS.

291. We arrange these groups under one category, because they evidently belong to one continuous and undisturbed life-period, and are all the sedimentary results of the ordinary operations of aqueous agency. It is quite true the percentage of living species is much less in the lower beds than it is in the middle or upper; but the number of identical species which runs throughout the whole, and the impossibility, in most districts, of making any lithological separation, renders it the safest and most intelligible plan to treat these three groups under one head, and the pleistocene or boulder-drift under another. The line of separation between these two great formations is broad and unmistakable; it is not so between the eocene, miocene, and pliocene series, and need not be attempted unless for the purpose of working out local details. Confining our remarks to the three lower groups, we find the composition and succession of their strata so extremely varied and irregular, that it is next to impossible to give anything

like a generally applicable description. This much may be said, that their areas are usually well defined, as if originally deposited in inland seas or estuaries; that they give evidence of frequent alternations of marine with fresh-water sediments; and, on the whole, are less consolidated than the rocks of older systems. They consist for the greater part of clays and sands, with interstratified limestones, gypsums, siliceous sandstones, calcareous grits, marls, and occasional beds of lignite.

Lithological Composition.

292. With respect to the composition and succession of the Eocene, Miocene, and Pliocene strata, the following synopsis of the English tertiaries will convey a better idea than any detailed description :—

PLIOCENE.	MAMMALIFEROUS CRAG of Norfolk and Suffolk.—Consisting of shelly beds of sand, laminated clay, and yellowish loam, with layers of flinty shingle reposing on the chalk, and generally covered with a thick bed of gravel, abounding in the bones of mammals: hence the name. RED CRAG of Norfolk and Suffolk.—A deep ferruginous shelly sand and loam, with an abundance of marine shells, frequently rolled and comminuted. CORALLINE CRAG.—A mass of shells and corals in calcareous sand; or compact, and forming flaggy beds of limestone, with bands of greenish marl. Some of the harder portions are used as building-stone.
MIOCENE.	Supposed, on palæontological grounds, not to be represented by any of our British strata, unless perhaps (according to Lyell) the leaf-beds of Mull and the lignites of Antrim belong to this period. The subject, however, is still open to doubt.
EOCENE.	FLUVIO-MARINE, or MARINO-LACUSTRINE BEDS of Hampshire and Isle of Wight.—Consisting of clays and marls, sometimes indurated, of sandy clays and subordinate layers of siliceous limestone. BAGSHOT SANDS.—A marine series of loose sands, sandstone, greenish sandy clay, and fissile marls. LONDON CLAY.—A brown or dark-blue or blackish tenaceous clay, with layers of argillo-calcareous nodules. Layers of greenish sand, and masses of gypsum, and iron-pyrites not unfrequent. BOGNOR BEDS.—Occur towards the base of the London clay, and consist of calcareous and siliceous nodules, or of coarse green indurated sand, with septaria and numerous marine shells. PLASTIC CLAY AND SANDS.—Composed of sand, shingle, mottled clays, and loam, with beds of rolled flints and marine shells.

Or, attempting with Professor Phillips to arrange the English

tertiaries into palæontological "periods," we should then have the annexed subdivisions and series :—

PLIOCENE.	CRAG PERIOD.—Cetacea, mastodon, rhinoceros, felis, lutra; shells numerous, of existing genera, frequently of existing species.	Littoral deposits on the shores of the German Ocean, when the land was at a somewhat lower level than now. Coralline and shell deposits farther from shore.

Discontinuity of succession here—Miocene strata not existing in Britain.

EOCENE.	UPPER MARINO-LACUSTRINE PERIOD.—Palæotherium, anoplotherium, chæropotamus, &c.; shells of existing genera.	Fresh-water and marine deposits of Hempstead and Bembridge in Isle of Wight.
	LOWER MARINO-LACUSTRINE PERIOD.—Shells of existing genera.	Fresh-water and marine deposits of Headon Hill.
	BARTON PERIOD.—Shells numerous, mostly of existing genera, but not often of existing species.	Marine, argillaceous, and arenaceous deposits.
	BRACKLESHAM PERIOD.	Arenaceous, argillaceous, and lignitic deposits.
	BOGNOR PERIOD.—Shells numerous, mostly of existing genera, rarely of existing species; land animals mostly of extinct genera—coryphodon, hyracotherium, didelphys, macacus.	Marine, argillaceous, and arenaceous deposits. Septaria.
	THANET PERIOD.—Shells few, analogous to those above, distinct from the mesozoic shells below.	Marine and fluviatile deposits, lignite, pebbles, coloured clays, and sands.

In studying the preceding synopsis, the student must not attach to these so-called "periods" an importance and significance that was never intended by Professor Phillips. It is by no means attempted to set up the Thanet or Bognor beds as the exponents of independent "life-periods;" but simply to imply that sectionally as well as palæontogically the one set precedes and is separable from the other, while all are component portions of one great cainozoic system. The term "stage" (*étage*) had been happier and more applicable, viewing the respective series as successive steps in a great formation, and regarding their fossil differences as arising more from local variations in the areas of deposit, and from other geographical conditions, than from any marked biological progression during the time of their deposition.

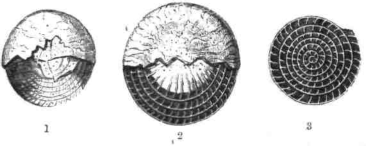
293. Taking the preceding tabulations as sufficiently descriptive of the London and Hampshire tertiaries, we may, for the sake of comparison, subjoin a section (in descending order) of the strata in the Paris basin, which are usually regarded as the equivalents of the English eocene, and which have long since been rendered

classic by the distinguished researches of Cuvier, Brongniart, Prevost, and D'Archiac :—

UPPER EOCENE.	
1. Calcaire de la Beauce, or upper fresh-water, and Grès de Fontainebleau.	Hempstead series.
MIDDLE EOCENE.	
2. Gypseous series and Middle fresh-water calcaire lacustre moyen.	Bembridge series.
3. Calcaire silicieux (in part contemporaneous with the succeeding group?)	Lower part of the Bembridge series.
4. Grès de Beauchamp, or Sables Moyens.	Osborne series and upper and middle part of Headon series.
5. Upper Calcaire Grossier (cailasse) and middle Calcaire Grossier.	Headon Hills sands, Barton, Upper Bagshot, and part of Bracklesham beds.
6. Lower Calcaire Grossier or Glauconée Grossière.	Bracklesham Beds.
7. Soissonais Sands, or *Lits Coquilliers*.	Lower Bagshot, intermediate in age between the Bracklesham beds and the London clay.
LOWER EOCENE.	
8. Argile Plastique et lignite.	Plastic clay and sand, with lignite (Woolwich and Reading series).

294. As with the Paris and English deposits, so with the other tertiary basins of southern France, Spain, Austria, Hungary, Italy, &c.—all of them exhibiting an irregular succession of clays, sands, limestones, marls, gypsum, and lignites, which, when examined lithologically and palæontologically, are clearly referable to the same period of formation. Among the most remarkable features of foreign tertiaries are the *infusorial* and *foraminiferal* strata—the former constituting such rocks as the "tripoli" of Bohemia and Virginia, and the latter the "nummulitic limestones" of the Old World, and the "orbitoidal" of the New. The tripoli consists almost entirely of the siliceous coverings of diatomaceæ, and is often of great thickness, as at Richmond in Virginia, where it is nearly thirty feet; while the nummulitic and orbitoidal limestones, mainly composed of coin-shaped (*nummus*, a coin) and globular (*orbis*, a globe) foraminiferous shells, are undoubtedly the most important of tertiary strata. Respecting the nummulitic limestone, which was till recently regarded as belonging to the cretaceous system rather than to the base of the eocene tertiaries, Sir Charles Lyell remarks, that "it often attains a thickness of many thousand feet, and extends from the Alps to the Apennines. It is found in the Carpathians, and in full force

in the North of Africa—as, for example, in Algeria and Morocco. It has also been traced from Egypt into Asia Minor, and across



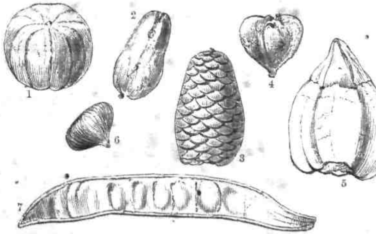
1, 2, Nummulites lævigata · 3, Section of do.

Persia by Bagdad to the mouths of the Indus. It occurs not only in Cutch, but in the mountain ranges which separate Scinde from Cabul; and it has been followed eastward into India." Another peculiar rock of the period is the so-called *indusial limestone* of Auvergne—a series of fresh-water strata, almost wholly composed of the cases or "indusiæ" of caddis-worms (the larvæ of *Phryganea*). We say so-called indusial limestone, for several entomologists entertain doubts as to this explanation of its origin, and would rather ascribe it to some chemico-concretionary action. Whatever its origin, the supposed insect-cases have been incrusted with carbonate of lime, like shells in recent shell-marl, and have subsequently been consolidated into a species of travertine. The rock is described as "sometimes purely calcareous, but there is occasionally an intermixture of siliceous matter; and several beds of it are frequently seen, either in continuous masses or in concretionary nodules, one upon another, with layers of marl interposed." Besides these indusial, infusorial, and nummulitic limestones, there are others of true *oolitic* texture (in the basin of the Limagne), and scarcely distinguishable from our older Bath stone, were it not for the land-shells and bones of quadrupeds interspersed through the mass.

Palæontological Aspects.

295. As already stated, the organic remains of the system are all of *cainozoic* types—that is, either closely resemble, or are identical with, existing genera and species. Of course, since the commencement of the Eocene period, many forms of life have died away, and it is to these extinct families, rather than to those still surviving, that we shall now direct attention. The FLORA of

European Tertiaries exhibits few marine species—the loose and unconsolidated nature of the deposits being unfavourable to their preservation ; but the fluvio- or lacustro-marine beds contain remains that can be referred to the lycopodiums ; to the palms, cycads, and coniferæ ; and to the leguminosæ, amentaceæ, and other true dicotyledonous families. Detached leaves, fruits, seeds, and seed-vessels are common in the clays of the London basin ; and the lignites of France and Germany exhibit abundant evidence of the dictoyledonous or true timber-tree structure. Such names as *lycopodites*, *flabellaria* (fan-palm), *carpolithes* (*carpos*, fruit), *cupressinites* (*cupressus*, the cypress-tree), *solenostrobus* (*strobilus*, a fir-cone), *faboidea* (*faba*, a bean), *leguminosites* (*legumen*, a pod), *tricarpellites*, *nipadites*, *mimosites*, *petrophiloides*, *chara*, and the like, sufficiently indicate the external appearance and supposed alliances of these vegetable fossils. As already men-



1, Cucumites variabilis ; 2, Faboidea semicurvilinearis ; 3, Petrophiloides variabilis ; 4, Cupanoides lobatus ; 5, Nipadites cordiformis ; 6, Legumenosites dimidiatus ; 7, Mimosites *Browniana*.

tioned, the great repositories of the Tertiary Flora are the *lacustrine* lignites, and from these M. Brongniart has obtained the following classified examples :—Cellular Cryptogams, *muscites* ; Vascular Cryptogams, *equisetites*, *filicites*, *lycopodites*, *chara* ; Gymnospermous Phanerogams, *pinus*, *taxites* ; Monocotyledonous Phanerogams, *smilacites*, *flabellaria*, *endogenites*, *poacites* ; and Dicotyledonous Phanerogams, *comptonia*, *betula*, *carpinus*, *phyllites*, *nymphæa*, *culmites*, *carpolithes*, and *exogenites*. On the whole, the flora of the European tertiaries is yet indifferently worked out, and, considering the close affinity of their plants to those of existing sub-tropical regions, the fact is by no means

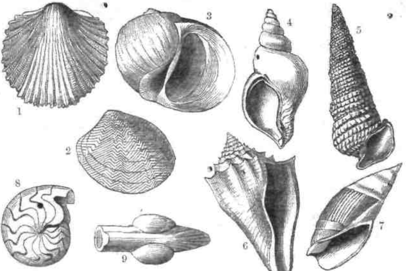
creditable to the science of Botany. The remains in the Bovey lignite, for example, are no doubt difficult of preservation, but when fresh taken up, their characters are often clear and well defined, and much good work might be done by a qualified botanist in the course of a single summer's residence. Of the Floræ of such tertiaries as the lignites of New Zealand and other distant localities we know little, as yet, beyond the fact that they differ in species from those now growing in the same regions, and seem to indicate, as in Europe, considerable climatic and geographical changes since the time of their deposit.

296. Of the FAUNA, the invertebrate orders—infusoria, foraminifera, corals, sea-urchins, star-fishes, serpulæ, barnacles, crustacea, and shell-fishes—are extremely abundant, both numerically and in point of species. Our limits will only permit us to mention a few of the more common genera—and these as occurring more especially in English and Continental strata. The foraminifera are perhaps most abundantly represented by *dentalina*, *nodosaria*, *nummulites*, *orbitoides*, *polymorphina*, and *calcarina*, *bi-*, *tri-*, and *quin-que loculina;* the alcyonia by *graphularia* and *alcyonium;* the corals by *turbinolia*, *paracyathus*, *dendrophyllia*, *caryophyllia*, &c.; the sea-urchins by *echinus*, *cidaris*, *hemiaster*, *echinocyamus*, &c.; the star-fishes by *astropecten* and *goniaster;* the crinoids by *pentacrinus* and *comatula;* the annelids by *serpula*, *spirorbis*, and *vermicularia*, &c.; the cirripeds by *balanus* and *pollicipes;* and the crustacea by such common forms as *pagurus*, *xanthopsis*, *holoparia*, *archæocarabus*, *cythere*, and *cytherella*. So closely related are many of the testacea to those of our present seas, that, as formerly stated, the groups *eocene*, *miocene*, &c., have been instituted on the percentage of existing shells found in their strata. Thus:

Pleistocene,	from	90 to 98	of living	species.
Pliocene,	,,	60 to 80	,,	,,
Miocene,	,,	20 to 30	,,	,,
Eocene,	,,	1 to 3	,,	,,

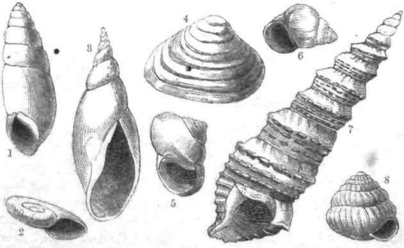
Of these some of the most persistent and widely distributed genera are the bryozoa, *eschara*, *flustra*, *lepralia*, *cellepora*, and *tubulipora;* the monomyaria, *ostrea*, *pecten*, *lima*, and *anomia;* the dimyaria, *cardium*, *astarte*, *tellina*, *corbula*, *arca*, *nucula*, *lucina*, &c.; the gasteropods, *cerithium*, *fusus*, *murex*, *pleurotoma*, *nassa*, *natica*, *voluta*, *pyrula*, *turitella*, *oliva*, *conus*, &c.; and the cephalopods, *nautilus* and *belosepia*. It is now, too, that we detect in these tertiary marls and clays the approximating species of our *lymneæ*, *paludinæ*, *planorbis*, and other fresh-water shells; the terrestrial snails, *helix*, *pupa*, *clausilia*, &c., so slenderly represented in other epochs—thus showing that marine, fresh-water,

and terrestrial conditions were ever concomitants, though the



1, Cardium porulosum ; 2, Nucula Cobboldiæ ; 3, Natica sigeracina ; 4, Fusus contrarius ; 5, Cerithium elegans , 6, Volutilithes spinosus ; 7, Ancillaria buccinoides ; 8, Nautilus zic-zac ; 9, Beloptera.

latter has been sorely obliterated by the superficial changes to which the older formations have been subjected. So closely allied,



1, Bulimus ellipticus ; 2, Planorbis discus ; 3, Lymnea longiscata ; 4, Cyrena cuneiformis , 5, Helix occlusa ; 6, Paludina lenta ; 7, Melania inquinata ; 8, Helix labyrinthica.

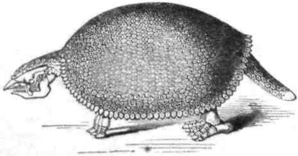
indeed, are many of the tertiary genera to the inhabitants of existing seas in one or other region of the world, that the best way to study their variations of form, is to arrange them *en suite* with the shells of the modern conchologist. By this method the

student will perceive at a glance the effects of climate and habitat on living races, and he will be enabled to trace down through the pliocene, miocene, and eocene strata that gradual departure from existing forms which "progress in time" seems to stamp on vital manifestations even over the same areas of the world, and where there is no apparent change in physical conditions to account for the onward mutation. With respect to the FISHES of the tertiary epoch, "they are so nearly related," says M. Agassiz, "to existing forms, that it is often difficult, considering the enormous number (above 8000) of living species, and the imperfect state of preservation of the fossils, to determine exactly their specific relations. In general, I may say that I have not yet found a single species which was perfectly identical with any marine existing fish, except the little species (*mallotus*) which is found in nodules of clay, of unknown age, in Greenland." The most common *ichthyolites* in the English tertiaries are the shark-like teeth of gigantic placoids, which seem to have thronged the waters, and are known by such names as *myliobatis*, *actiobatis* (ray), *lamna*, *carcharodon* (shark), *pristis* (saw-fish), *otodus*, &c. Of the ganoids we have such forms as *phyllodus*, *lepidosteus*, and *accipenser* (sturgeon); of cycloids, *cœlorhynchus* (sword-fish), *cœlopoma*, *bothrosteus*, and *goniognathus*; and of ctenoids, *cœloperca*, *percostoma*, *eurygnathus*, and *sciænurus*. In the fresh-water lignites the genera *perca* (perch), *mugil*, *leusciscus*, and *cyprinus* (carp), are perhaps the most abundant. Among the REPTILES the most common are the fresh-water and marine turtles (*chelone*, *emys*, *trionyx*, and *platemys*); true analogues of the existing crocodile and gavial (*crocodilus*, *gavialis*, and alligator); and sea-snakes (*palæophis* and *paleryx*). Of BIRDS several species have been described, chiefly from the Paris tertiaries. Of these the eocene conglomerates of Meudon have yielded remains of a gigantic bird (*gastornis Parisiensis*) apparently intermediate between the wading and aquatic orders (the tibia indicating a bulk fully equal to that of the ostrich); and in the miocene strata have been found several others that would seem to be connected with the genera buzzard, quail, curlew, heron, sea-lark, kingfisher (*halcyornis*), pelican, and vulture (*lithornis*); while many unknown fragments of bird-bones are merely as yet ranked under the general term *ornitholites*. Of the MAMMALIA every existing order has had its tertiary representatives—that is, if we include in this category all the strata and accumulations which occur between the older eocene and the "newer" pliocene that lies immediately beneath, and in some instances inosculates with, the "glacial or northern drift" of the pleistocene epoch. It must be remembered, however, that, though

certain forms run throughout the entire system, many are specially characteristic of the eocene and miocene, while others do not appear till towards the close of the pliocene, or even the commencement of the pleistocene epoch. Of course, the intelligent student is now prepared for such gradations and advances during every geological era; and though there can be no satisfactory working out of details without such divisions and stages, it is enough for the purposes of a general elementary outline to note merely the leading forms that belong to the system. Thus the Cetacea (whales) are represented by several species, as *balæna*, *balænodon*, *zeuglodon*, and *cetolites* or fossil ear-bones of unknown species; the Edentata (toothless animals) by gigantic analogues of the sloth, armadillo, and ant-eater, as *megatherium* (great wild

Megatherium.—From the Upper Tertiaries of South America.

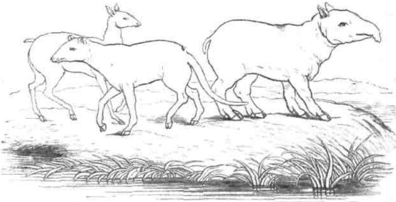
beast), *megalonyx* (great-claw), *glyptodon* (sculptured-tooth), *toxo-*



Glyptodon Clavipes—From the Upper Tertiaries of South America.

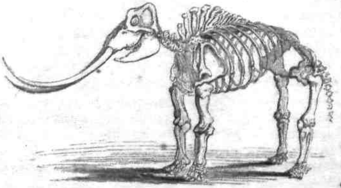
don (bow-tooth), *mylodon* (mill-tooth), *pachytherium*, &c.; the Ruminantia (cud-chewers) by several species of elk, stag, antelope, buffalo, ox, &c., as *xiphodon*, *dichobune*, *cervus megaceros*, *urus*, &c., and by some curious intermediate forms, uniting, as

it were, the characters of ruminants and pachyderms, as *sivatherium* (from the Sivalik range in India), *ocrodon*, and *encrotaphus*, the camel-like *merycotherium* from the Siberian drift, and the llama-like *macrauchenia* from the pampas of Brazil; the Pachydermata (thick-skins) by numerous uncouth tapir-like forms, as *palæotherium* (*palaios*, ancient, *therium*, wild beast), *anoplotherium* (*anoplos*, defenceless), *deinotherium* (*deinos*, terrible), *paloplotherium*, and *coryphodon* — hog-like genera, as



Restored Outlines—Xiphodon, Anoplotherium, Palæotherium—Eocene Tertiaries of Paris Basin.

hyracotherium, *chæropotamus*, and *hyopotamus*—intermediate or compound forms, as *dichodon*, *pæbrotherium*, &c.—allies of the rhinoceros and hippopotamus, as *acerotherium* and *archæotherium* —and true elephantoid genera, as the *mastodon* and *mammoth*;



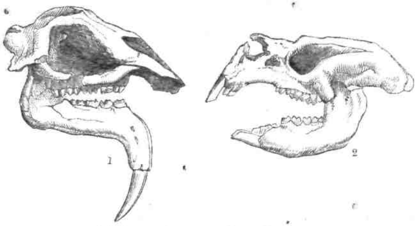
Mastodon —Upper Tertiaries of Northern Hemisphere

the Rodentia (gnawers) by a number of species, chiefly from the Paris miocenes, allied to the beaver (*castor*), hare (*lepus*), rat

(*lagomys*), squirrel, &c.; the Carnivora (flesh-devourers) by species akin to the lion (*felis*), bear (*ursus spelæus*), hyæna (*hyænodon*), intermediate between the hyæna and tiger (*macairodus*), otter (*lutra*), fox, seal, &c.; the Insectivora (insect-eaters) by remains of a species of mole (*spalacodon*); the Cheiroptera (hand-winged) by two or three species of bat from the gypsum beds of Montmartre (*vespertilio*); the Marsupialia (pouch-nursing) by several species allied to the kangaroo and opossum (*didelphys* and *macropus*), and some pachyderm-like representatives of the same great group as *diprotodon* and *nototherium*; and the Quadrumana (four-handed) by several examples (*pliopithecus, dryopithecus, mesopithecus*) from the miocene beds of France and Greece, and so called from their apparent affinity to the tailed monkeys of Southern Asia; as well as a genuine *macacus*, or ape, from the pliocene and eocene deposits of England. Thus, every order of mammal, with the exception of man, has its representative during the tertiary epoch—differing it may be in certain species, but still presenting on the whole such a facies of resemblance, that one feels that he is approaching the confines of existing nature.

297. Contrasting the fauna of the Tertiary with those of earlier epochs, the student cannot fail to perceive that its grand distinguishing feature was the prevalence of mammalian life; and comparing these mammalia with those now peopling the globe, he must be struck with the frequency of compound or intermediate forms. At present, many of our zoological *families* link one into the other by the finest gradations; during the tertiary epoch, similar connecting-links seem to have prevailed between the most distant mammalian *orders*; and thus we are presented with cetacean-like pachyderms, pachyderm-like ruminants, and ruminants that seem to coalesce with the edentates and rodents. Among these curious forms we may notice the *anoplothere*, which combines the pachydermal characters of the tapir with the lightness and agility of the ruminant gazelle; the *deinothere*, with its elephantal trunk and morse-like tusks, affording a new and important link between the cetaceans and pachyderms; the *halithere*, that connects still more closely the quadrupedal hippopotamus with the natatorial dugong; the *anthracothere*, that stands intermediate between the river-hog and hippopotamus; the *macrauchenia*, which forms a new link between the aberrant group of ruminants to which the camel and llama belong and the true pachyderms; the gigantic *sivathere*, with its prehensile trunk and four-horned skull, exhibiting at once the adaptations of the elephant and the defences of the ruminant antelope; the *elasmothere*, that connects the bulk of the ungulate rhinoceros with the swift-

ness of the solid-hoofed horse; and the carnivorous *machairodus*,



1, Deinotherium giganteum; 2, Diprotodon.—Australia.

that combines the size and weight of the grizzly bear with the trenchant dentition of the Bengal tiger. These, and many more described by Cuvier, Kaup, Owen, Falconer, and others, open up new and extensive fields of speculation to the anatomist and physiologist, convincing them more and more that a comprehensive and satisfactory scheme of Biology will never be obtained till the discoveries of the palæontologist are grafted upon and interwoven with the classification of the zoologist.

Physical and Geographical Features.

298. With respect to the extent and distribution of the lower tertiaries—laying aside the nummulitic limestone, which is in some respects a peculiar and doubtful development—we have as yet no certain knowledge. As there is often no perceptible mineral distinction between many clays, sands, and gravels, it is only by their imbedded fossils that geologists can determine their tertiary or post-tertiary character. Many accumulations at present regarded as superficial may be found hereafter to be of older date; and thus it becomes difficult to fix with certainty the geographical limits of the system. So far as Europe is concerned, tertiary deposits have received considerable attention, and their area has been found to be much more extensive than was at one time supposed. In general, the deposits occupy well-defined tracts or basins; hence the frequent reference in works on geology to the "London basin," "Hampshire basin," "Paris basin," "Vienna basin," and other tertiary areas in Europe. As far as discovery has gone, there are few countries in which ter-

tiary strata have not been detected (see Recapitulatory tabulation); and while we regard those of England, France, Austria, and Italy as typical, we must ever bear in mind that considerable modifications may require to be made, as the tertiaries of India and North and South America come to be more closely examined.

299. One important fact must not be lost sight of in drawing any general conclusions from the distribution of tertiary deposits —viz., that as the fauna and flora of the period approach in character the fauna and flora of existing nature, and that as the plants and animals of Europe, India, Australia, South America, &c., all differ widely from each other, so may we expect similar differences among the fossil remains of these distant regions. And this, as will afterwards be seen, is fully borne out—the tertiary mammals of South America resembling the sloths, armadilloes, ant-eaters, and alpacas of that continent; those of Australia its marsupial kangaroos and opossums; those of New Zealand gigantic wingless birds like the apteryx; while those of the Old World have more immediate relationship to its elephants, rhinoceroses, horses, deer, and oxen. A few genera, indeed, as the mastodon and horse, seem to have enjoyed a wider range—fossil species being found simultaneously in Europe, Asia, and North and South America; but this can scarcely invalidate the great generalisation expressed by Professor Owen, "that in the highest organised class of animals the same forms were restricted to the same great provinces at the Pliocene period as they are at the present day." And here it may be remarked that the student cannot too early direct his attention to the laws which regulate the distribution of life on the globe, and be able to distinguish clearly between *identity* and *representation* of species. During the Palæozoic and Mesozoic epochs there appears to have been a greater identity of species over wide areas; during the present period the areas are more circumscribed, and the species in one region are only the representatives of those inhabiting another—that is, are specifically different in form, but discharge the same functions in the economy of nature. Thus the elephant of India is only represented by, and not identical with, the elephant of Africa; the lion and tiger of Asia are represented by the puma and jaguar of America; and the African ostrich finds its representative in the emu of Australia.

[A curious resemblance between the flora and fauna of Tertiary Europe and those of modern North America, has been indicated by Professor Agassiz—a resemblance which forcibly recalls that which was formerly instituted by Professor Owen, between the Life of the Oolite and that which now exists in the continent of Australia. Such reproductions, or rather *shiftings in time, of the facies of life over different areas of the globe*, is evidently suggestive of some great law, could science only determine the facts,

and grasp their multifarious relations. "If we compare," says Agassiz, in his *Lake Superior*, "the fossil trees and shrubs from the Tertiary beds of Œningen with a catalogue of the trees and shrubs of Europe and North America, it will be seen that the differences scarcely go beyond those shown by the different floras of these continents under the same latitudes. But what is quite extraordinary and unexpected is the fact, that the European fossil plants of that locality resemble more closely the trees and shrubs which grow at present in the eastern parts of North America, than those of any other part of the world; thus allowing us to express correctly the difference between the opposite coasts of these continents, by saying that the present eastern American flora, and I may add the fauna also, have a more ancient character than those of Europe. The plants, especially the trees and shrubs growing in our days in the United States, are, as it were, old-fashioned; and the characteristic genera, Lagomys, Chelydra, and the large Salamanders with permanent gills, that remind us of the fossils of Œningen, are at least equally so!—*they bear the marks of former ages.*"]

300. The igneous rocks associated with the system may, with the exception of a few doubtful cases, be ranked as Volcanic or post-trappean products. In England the tertiary strata have suffered no internal change from igneous action, though, since their deposition, vast displacements have taken place, giving rise to the synclinal basins of London and Hampshire, and the inclined and even vertical strata of the Isle of Wight. In Scotland the (miocene?) leaf-beds of Mull are interstratified with igneous tufas; and the Hebrides generally, as well as the opposite coasts of Ireland, give evidence of volcanic activity during the deposition, or at all events towards the close, of the pliocene series. In Central France (Auvergne), along the Rhine, in Switzerland (the Alps), in Hungary (the Carpathians), and in Italy, there are ample evidences of volcanic activity during the deposition of the system, and of enormous displacements and elevations subsequent to its close. "When we have once arrived at the conviction," says Lyell, "that the nummulitic formation occupies a middle place in the eocene series, we are struck with the comparatively *modern date to which some of the greatest revolutions in the* physical geography of Europe, Asia, and North Africa must be referred. All the mountain-chains, such as the Alps, Pyrenees, Carpathians, and Himalayas, into the composition of whose central and loftiest parts the nummulitic strata enter bodily, could have had no existence till after the Middle Eocene period. During that period, the sea prevailed where these chains now rise; for nummulites and their accompanying testacea were unquestionably inhabitants of salt water. Before these events, comprising the conversion of a wide area from a sea to a continent, England had been peopled by various quadrupeds, by herbivorous pachyderms, by insectivorous bats, by opossums and monkeys. Almost all the extinct volcanoes which preserve any remains of their original form, or form the craters from which lava

streams can be traced, are more modern than the eocene fauna; and besides these superficial monuments of the action of heat, Plutonic influences have worked vast changes in the texture of rocks within the same period. Some members of the nummulitic and overlying tertiary strata called *flysch* have actually been converted, in the Central Alps, into crystalline rocks, and transformed into marble, quartz-rock, mica-schist, and gneiss." The crateriform hills of Auvergne and the Rhine present the finest examples of the latest igneous efforts of the period, and form as it were a connecting lithological link between the secondary traps and the products of existing volcanoes. In their mineral composition the tertiary traps are chiefly trachytic—graduating from a compact felspathic greystone to a scoriaceous tufa, but in no instance presenting the dark, augitic, and basaltiform structure of the carboniferous traps, nor the amygdaloidal and porphyritic texture of those associated with the old red sandstone and silurian strata.

301. Respecting the distribution of sea and land, and the climatal conditions of the world during the deposition of the tertiary strata, it is difficult to arrive at any satisfactory conclusion. It is certain, however, that one or other of the groups is to be found in every region of the globe; that in some instances they are strictly marine, and in others as decidedly fresh-water; while in many basins, as in England and France, they are partly fresh-water and partly marine, as if there had been frequent submergences and elevations, or, at all events, periods when fresh-water inundations prevailed in the areas of deposit. As to physical conditions, the cycads and palms and monkeys of the London basin give evidence of a genial climate—a fact further corroborated by the huge pachyderms of the Paris strata, the gigantic edentata of South America, and the larger marsupials of Australia. On the whole, there seem to have been wide areas of shallow seas thronged with the humbler as well as higher forms of marine life; low sunny islands crowned with cycads and palms; broad estuaries prowled in by sharks, and tenanted along shore by herds of halitheres and deinotheres; rivers swarming with gavials and crocodiles; lagoons and fresh-water lakes thronged with anthracotheres and hippopotami; dense marshy jungles for the palæothere and rhinoceros; vast forest-wilds and grassy pampas, where roamed the mastodon and mammoth, or lazily squatted the megathere, mylodon, and glyptodon; open pasture plains for the sivathere, urus, and buffalo; and still higher and drier regions where the notothere, merycothere, and macrauchenia foraged for a coarser and scantier subsistence. All these conditions are not found, however, in any one locality, or under the same latitudes

—there being then, as now, restricted areas beyond which certain families never passed; and thus it is that we can account for the fauna of different tertiary areas—the life of these areas bearing some resemblance to the life that now peoples the same geographical regions. Looking at the gradually decreasing areas of life-distribution as we ascend in the geological scale, it would almost seem to be part of some great cosmical law, that the lowlier organisations of primeval epochs had wider ranges than the higher organisations of later epochs, and just as vitality became more specialised in its forms and functions, so the areas of distribution become more restricted and numerous. And this seems to hold good epoch after epoch, till Man appears on the stage, and confers on certain families (the domesticated animals) a portion as it were of his own cosmopolitan nature and range of adaptability.

Industrial Products.

302. The industrial products of the system are building-stone and marbles of various quality; limestones of considerable value; pipe, potter's, and brick clays in abundance; gypsum, or the well-known "plaster of Paris;" and the highly-valued *burr* millstone, which is obtained from the upper fresh-water limestones of the Paris basin, as well as from the eocene beds of the Southern States of America. Lignite or "brown coal" is also worked in several tertiary districts, as in France, Germany, New Zealand, and at Bovey Tracy in Devonshire; and amber and retinasphalt, which are fossil gums or gum-resins, are likewise obtained from the lignitic beds of the series. As the Bovey beds are the only tertiary lignites worked in Britain (being used for the potteries of the district), and as they form, moreover, an intermediate lithological stage between the true coals and modern peat-moss, we may notice their mode of occurrence, as described by Dr Miller, and corroborated by our own investigations. "The whole series dips to the south and south-east about 20 inches in a fathom. The perpendicular thickness of these strata, including the beds of pipe-clay with which they are interstratified, is about 70 feet. There are about six of each, and they are found to continue eastward in an uninterrupted course to the village of Little Bovey, a mile distant, and probably much farther. The strata of lignite near the surface are from 1½ to 4 feet thick, and are separated by beds of brownish unctuous clay nearly of the same dimensions, but diminishing in thickness downwards, in proportion as the lignites grow thicker; and both are observed to be

of a more compact and solid substance in the lower beds. The lowermost stratum of coal is 16 feet thick [its thickness is not persistent]; it lies on a bed of clay, under which is a sharp greensand of 17 feet thick, and under that a bed of hard coarse clay, into which they have bored, but found no coal. From the sand arises a spring of clear blue water, which the miners call 'mundic water,' and a water of the same kind trickling through the crevices of the coal tinges the outside of it with a blue cast, derived from phosphate of iron. Amongst the clay, but adhering to the coal, are found lumps of a bright yellow loam (retinasphalt), which burn with an agreeable scent [the lignite itself burning with a stifling disagreeable odour]. Some of the coal is black, and nearly as heavy as pit-coal—this is called 'stone-coal;' the most remarkable resembles wood in the grain [flabelliform leaves, coniferous wood, &c.], so much as to be called 'wood or board coal' [and some layers consist entirely of compressed leaf-matter, like the *papier kohle* of Germany]. Some plants, like grass and reeds [junceæ, phragmites ?], lie in the alternating clays which are in part carbonaceous."

II.—PLEISTOCENE GROUP.

303. This group, as the name implies, is intended to embrace all tertiary accumulations, the organic remains of which are chiefly referable to existing species. In the present state of geological knowledge, it is impossible to define with precision the limits of pleistocene tertiaries, and all that can be attempted is to arrange under one head the clays, sands, gravels, and boulders generally known as the "drift formation." One thing is certain, namely, that while the eocene, miocene, and pliocene strata were gradually, and during a long series of ages, deposited in seas, estuaries, and lakes, surrounded by lands that enjoyed a genial and equable climate, some immense changes, physically and geographically, took place over these areas, which brought the pliocene to a close, and heralded the advent of the pleistocene era. The distribution of pliocene seas and lands over a large portion of the northern hemisphere seems to have been somewhat suddenly broken up, the climate was changed, and the huge mammalia that browsed in thousands in the jungly valleys, and roamed over the wooded plains, met with a rapid and all but total extinction. We have already alluded to the extensive dislocations that succeeded the deposition of the stratified tertiaries in England, and to the upheaval, in greater part, of such gigantic mountain-ranges as the

Pyrenees, Alps, Atlas, Carpathians, and Himalayas; and clearly to some such vast revolution as this is to be ascribed the total change of climatal conditions, all over these latitudes, that accompanied the accumulation of the Pleistocene clays, gravels, and boulders. The ordinary depositions of marine and marino-lacustrine sediments are brought to a close, the shell-fish that thronged the waters die and are swept together in miscellaneous masses, the elephantoid and other pliocene mammals succumb to the rigours of an arctic climate, and their bones are drifted together in mounds of "ossiferous gravel" and "ossiferous breccia," or piled into caves ("bone-caves") that were formerly the lairs and hiding-places of their carnivorous contemporaries. It is usual to treat these ossiferous gravels and cave-deposits as belonging to a "*Preglacial period*," intermediate between the true pliocene and pleistocene deposits; but as the time was one chiefly characterised by its local extinctions, it were better to regard it not as an independent life-period, but merely as the capping or close of the Pliocene, to whose forms of vitality all its broken and mutilated fragments belong. And yet we must be careful to note, that this apparently sudden transition from Pliocene to Pleistocene is at the most but a local and partially explained phenomenon; for when we turn to the North American continent we find a continual refrigeration taking place during the Pliocene period, as evidenced by the disappearance of southern and the gradual appearance of more northerly forms of mollusca.

Ossiferous Gravels, Breccias, and Caverns.

304. Adopting this view, we may state in very general terms, that above, and of more recent date than, the newest pliocene lignites, clays and marls occur in many parts of the northern hemisphere, accumulations of drifted shells; gravels replete with bones of terrestrial and marine mammals (ossiferous gravels); cemented and stalagmitic bone-breccias in caves and fissures (osseous breccias); and caverns in limestone ridges filled with bones imbedded in ochraceous mud or stalagmite, some of these the skeletons of animals that had laired and died there, and others that had been dragged thither and devoured by carnivora, or had been drifted by waves and currents, while the sea and land stood at varying and variable levels. These phenomena are clearly the results of the physical revolutions that brought the Pliocene epoch to a close, and though the remains differ considerably from those of the lower tertiaries, and approximate more closely to recent

species, still their general facies is tertiary, and so many of them are extinct, that it would only be multiplying subdivisions not warranted by nature, to regard them as the creations of an independent epoch. Attempting to separate the "drifts" or "glacial epoch" from the human period on the one hand, and from the true tertiaries on the other, Professor Phillips arranges the Pleistocene thus:—

c. Postglacial Period.—Peat deposits, limestone deposits, river deposits, sea-beaches. (*The red deer, long-fronted ox, Irish elk, urus priscus, hippopotamus, elephant, forests of modern trees.*)
b. Glacial Period.—Marine deposits, clay with irregular stones drifted from a distance, partially worn or rolled pebbles or erratic blocks, gravel beds, shell beds interspersed. (*Marine shells of Arctic type.*)
a. Preglacial Period.—Local drifts of gravel and sand, lacustrine marls, bone deposits in caves. (*Forests of modern trees, Irish elk, elephant, hippopotamus, hyæna, felis spelæa, cavern bear, &c.*)

To this proposed arrangement it must be objected that we have not yet sufficient evidence to prove that MAN was not the contemporary of the Irish elk, urus, long-fronted ox, and elephant in Europe; and even if we had, it is far from decided that he was not their contemporary in wide regions of Asia, as yet insufficiently examined by the geologist. Again, there are really almost insuperable difficulties connected with the separation of the so-called glacial beds; for this reason, that during the downward and the upward movements of the land the same clays, gravels, and breccias were more than once deposited, retransported, and again settled in the positions we now find them. All that we shall therefore attempt is to state the occurrence, between the stratified pliocene and the unmistakable boulder-drift, of these ossiferous gravels, breccias, and cave-deposits, noting that they contain the remains of a greater number of recent mammals than are found in any of the subjacent tertiaries. It may also be remarked, that as many of these caves and fissures are of vast antiquity, their lower floors contain the remains of pliocene or post-pliocene genera; the middle deposits the remains of true pleistocene species; while the upper layers of mud and stalagmite imbed the bones, charred wood, and rude stone implements of the human race. Their epoch, therefore, as regards their organic remains, is partly pleistocene, and partly recent; and though the caves themselves were originally excavated by pliocene waters, most of them have undergone extensive changes alike during the pleistocene and current eras. Though treated under the present section, the student must learn to regard many of these ossiferous caves and breccias as exponents both of the pleistocene and post-tertiary epoch, and not to confound them, as some

are in the habit of doing, with phenomena solely of tertiary antiquity.

305. The most remarkable *ossiferous caverns* in England, according to the authority just quoted, are Kirkdale Cave near Kirkby Moorside in Yorkshire, the Dream Cavern near Worksworth in Derbyshire, Banwell Cave in the Mendip Hills, Kent's Hole, and that of Brixham, discovered in 1858, near Torquay, Oreston near Plymouth, Cefn near Denbigh, and Paviland near Swansea. In Germany the slopes of the Harz mountains give us the caves of Baumann, Biel, and Schwarzfeld ; between the Harz and Franconia is the Bear Cavern of Glucksbrunn ; the Jura formation near Baireuth is celebrated for the rich associated caverns of Gailenreuth, Wunderhole, Rabenstein, Kahlock, Zahnloch, Schneiderloch, &c. In Westphalia, the same oolitic formation has the caves of Kluterhole and Sandwich. The caves of Adelsberg in Carniola, and the Dragon's caves in Hungary, have also yielded bones. In France, instructed by Dr Buckland's researches, two caverns, rich in bones, have been described by M. Thirria, near Vesoul, and several others near Narbonne by Marcel de Serres, Tournal, Christol, &c., and one near Miremont by M. de la None. Ossiferous caverns we now also know in Canada, the United States, Australia, and, in fact, in every region where the strata are favourable for the formation of such repositories. *Osseous breccia* appears singularly connected with the coasts of the Mediterranean. It occurs at Gibraltar, in Languedoc, and at several other points in the south of France, at Antibes, Nice, Pisa, Cape Palinurus, north of Bastea in Corsica, Cagliari in Sardinia, Meridolee in Sicily, in Dalmatia, &c. Ferruginous breccia, in which bones are associated with pisolitic iron ore, occurs in Würtemberg, and in Carniola in Jura limestone. Such are the chief of these curious repositories, whose characteristic mammalian remains may be briefly tabulated as follows :—

Pachyderms.—Elephas primigenius, Mastodon angustidens, &c. Hippopotamus major, Chæropotamus, rhinoceros tichorhinus, &c. Tapir giganteus, Sus fossilis, &c.

Solipeds.—Equus fossilis.

Ruminants. —Cervus megaceros, antelope, urus, bos primigenius and longifrons, merycotherium Sibericum, &c.

Carnivors.—Felis spelæa (*spelæa*, a cave), hyæna spelæa, and the peculiar hardened excrement, *album græcum*, of the hyæna, machairodus cultridens, ursus spelæus, gulo spelæus, wolf, fox, polecat, weasel, otter, &c.

Rodents.—Porcupine, beaver, arvicola, rat, lagomys, hare, rabbit, &c.

Edentates.—Megalonyx, megatherium, macrauchenia, manis giganteus, &c.

In the preceding list several of the species are decidedly distinct from those now existing ; others, again, show so little variation,

either in form or size, that it is impossible to make any distinction beyond that which will always arise from locality, individual constitution, and other minor influencing causes. The truth is, the palæontologist is now so closely on the confines of existing nature, that he finds it better to note the dropped-out links than attempt specific distinctions on such slender variations as present themselves in these pleistocene cavern-remains.

Boulder Clay or Glacial Drift.

306. As a whole, there is no formation more perplexing, or whose origin is involved in greater obscurity, than this "glacial drift" or "boulder clay"—the "diluvium" of the earlier geologists. Composed in some districts of irregular ridges and mounds of sharp gravelly sand; in some of expanses of pebbly shingle; in others of alternations of shingle, sand, and earthy debris; and more generally, perhaps, of various coloured clays, enclosing, without regard to arrangement, water-worn blocks or *boulders* of all sizes, from a pound to several tons in weight,—it is evident *that it does not owe its origin to the ordinary sedimentary operations of water*. It is also for the most part unfossiliferous; marine shells, chiefly of arctic type, being found, and that very sparingly, only in certain sands and clays apparently belonging to the same epoch. Under these circumstances it will be sufficient for the purposes of the student to describe the leading phenomena connected with its occurrence in the British Islands and north of Europe; to direct his attention to some of the theories that have been advanced to account for its formation; and then to refer him to a few of the leading monographs on the subject for such details as are necessarily beyond the limits of an elementary text-book.

307. It has been already stated that the group now under review consists of accumulations of clays, sands, gravels, and boulder-stones—the latter sometimes lying detached or in masses, but more frequently enclosed in the clays without regard to gravity or any other law of arrangement. We say "accumulations of clays, sands," &c., because these seldom or ever appear in regular strata, but here in masses, and there spread over wide tracts, as if brought together by some unusual and extraordinary operation of water. These unusual appearances have long and largely engaged the attention of observers; hence the variety of designations, such as "*diluvium*," "*diluvial drift*," "northern drift," "glacial drift," "erratic-block group," and "boulder-for-

mation." When we examine the group as it occurs in Britain, we find it in some tracts (eastern counties of England) an open gravelly drift, consisting of fragments of all the older rocks, from the granite to the chalk inclusive. In other districts, as the middle counties of Scotland, large areas are covered with a thick, dark, tenacious clay, locally known by the name of "till," and enclosing rounded and water-worn boulders, as well as angular fragments of all the older and harder rocks—granite, gneiss, greenstone, basalt, limestone, and the more compact sandstones. The boulders are of all sizes—from pebbles of a few pounds to masses of 20, 40, and 60 tons weight—are most frequently rounded and water-worn, and are distributed throughout the mass without any regard to sedimentary disposition. In other localities, both in England and Scotland, we find large areas covered by loose rubbly shingle and sand; the shingle and sand often appearing in mound-like ridges (*moraines*), or in flat-topped irregular mounds, as if the original gravelly deposit had been subsequently furrowed and worn away by currents of water. Occasionally districts are thickly strewn with boulders which rest on the bare rock-formations, without any accompanying clays or sands; and at times only a single gigantic boulder, or a few "perched blocks," will be found reposing on some height as evidence of the drift formation. These perched blocks are often of stupendous size. Dr Kane mentions one of rounded syenite, more than 60 tons, resting 100 feet above the level of the sea in Greenland; and we have measured several of nearly equal dimensions resting at still higher elevations on the metamorphic schists of the Perthshire Grampians. Perhaps one of the largest known detached boulders was that which now forms the pedestal to the statue of Peter the Great at St Petersburg, and which, when found in the morass where it originally lay, was estimated to weigh 1500 tons!—a weight which, however enormous, is fully equalled by several others that have been measured in the drift of Northern Europe and North America. When we come to examine the clays and sands more minutely, we find them partaking less or more of the mineral character of their respective districts. Thus, the boulder clays of our coal-fields, though thickly studded with boulders of distant and primitive origin, are usually dark-coloured, and contain fragments of coal, shale, and other carboniferous rocks. The same may be remarked of old and new red sandstone districts, where the clays and shingly beds are usually red; and of oolitic and chalk tracts, where they assume a yellowish or greyish aspect.

[The distribution of boulders or erratics over the area explored (says Professor Hind in his account of the Assiniboine and Saskatchewan Expedition) may be traced, as in Canada, to at least two epochs—the Drift and Boulder period, during which by far the larger number were torn from the parent rock and carried by ice to their present resting-places; and the Recent period, including the rearrangement of ancient drift, and the distribution of fresh supplies by the action of lake and river ice. The largest boulder was seen in the valley of the Qu'appelle. The circumference of this enormous erratic is 78 feet, and it exposes a portion above ground at least 14 feet in altitude. The next largest, one of limestone, was seen on the prairies below the Moose Woods. It is about 16 feet high, and at least 60 feet in circumference, is very jagged, and consists of immense slabs, whose edges project two and three feet. Near it are many others of the same kind, but of smaller dimensions. Near Little Cut Arm Creek, an affluent of the Qu'appelle, large unfossiliferous boulders are very numerous. North of the Assiniboine, near the Big Ridge, boulders are also abundant, and, when magnified by refraction, look like tents on the level prairies.]

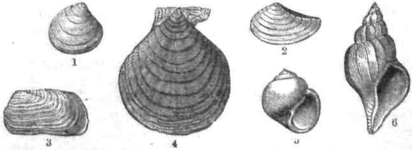
308. In addition to what has been stated respecting the composition of the drift, it may be remarked that the sands seldom exhibit lines of stratification, and that the clays are rarely or ever laminated. Occasionally sands and clays alternate, or a dark-coloured clay may be overlaid by a lighter-coloured one; but more frequently sands and clays occur *en masse*, enclosing curious "nests" or patches of gravel, and crowded accumulations of boulder-stones. On examining the surfaces of many of these boulders, we find scratches and groovings, as if they had been rubbed forcibly over each other in one direction; and, what is still more curious, the surfaces of the rocks on which the boulder clay reposes are all less or more smoothed (*roches moutonnées*), and marked with bold linear scratches and furrows, as if the boulders had been forcibly carried forward, and had scratched and grooved them during the passage. Again, these ruts and groovings all trend in one direction, and that generally in lines parallel to the hill-ranges and valleys in which they occur. Moreover, most of the hills, as in Britain, present a bare bold craggy face to the west and north-west, as if worn and denuded by water, while their slopes to the east and south-east are usually masked with thick accumulations of clay, sand, and gravel. This appearance, generally known by the name of "crag and tail," is ascribed to the same moving forces or currents which transported the enormous boulders of the Drift, and furrowed the surfaces of the rock-formations over which they were borne.

309. Taking all these phenomena into account, it is quite clear that pleistocene accumulations owe their origin to no ordinary operations of water. We can conceive of no current sufficiently powerful to transport boulder blocks of many tons

in weight over hill and dale for hundreds of miles; of no sedimentary conditions that would permit boulders and clays to be huddled up in the same indiscriminate mass; while the smoothing and grooving of rock-surfaces point to long-continued action, and not to any violent cataclysm in nature, even could we conceive of one sufficiently powerful to transport the blocks and boulders. There is only one set of physical conditions with which we are acquainted sufficient to account for all the phenomena—namely, arctic lands with glaciers and avalanches to wear and waste, and arctic seas with icebergs and ice-floes to transport the eroded material; and it is now to such conditions that geologists turn for a solution of the boulder formation. After the deposition of the pliocene tertiaries, it would seem that the latitudes of Britain and the north of Europe underwent a vast revolution as to climate, and that some new arrangement of sea and land took place at the same period. At all events, the large mammalia of the earlier tertiaries disappeared, and the land was submerged to the extent of several thousand feet, for we now find water-worn boulders on the tops of our highest hills, or, at all events, at an altitude of 1800 and 2000 feet. A cold period ensued, and icebergs, laden with boulders and gravel from other regions, passed over these latitudes, and dropped their boulders on our then submerged lands. How long this process continued it is impossible to determine; but by-and-by a gradual elevation of the submerged lands took place; our hill-tops and ranges appeared as islands; and our valleys as firths and straits. These islands were now covered periodically with glaciers; during a brief summer avalanches descended, glaciers smoothed the hill-sides and left the debris as *moraines* of sand and gravel; while the icebergs and ice-floes ground their way through the firths, *smoothing* ("dressing," as it is sometimes termed) and *grooving* the surfaces of opposing rocks, and dropping, as they melted away, their burdens of silt and boulders on the deeper sea-bottom. As the elevation continued, new surfaces were exposed, the western fronts of our hills were wasted by waves and swept bare by currents, and the soft material of the sea-bottom, as it rose above the waters, was washed away and carried to areas of sea-bottom not yet elevated above the waters. We say the "western," or rather "north-western," front of our hills; for taking the phenomena of crag and tail into account, the direction of the groovings on rock-surfaces, and other kindred appearances, it is evident that in Britain the transporting currents passed from north and west to south and east. It is thus that

we find granitic and gneiss boulders from the Scottish Highlands now spread over the plains of Fife and Mid-Lothian, and blocks from the hills of Cumberland scattered over the moors of Yorkshire. In the north of Europe the drift has taken a more southerly course, and thus boulders from Lapland and Finland are spread over the plains of Russia and Poland, and granites from Norway now repose on the flats of Denmark and Holstein. Occasionally, as in Switzerland, the drift appears to radiate from a centre; and this we can readily conceive, as the Alps rose isolated in a glacial sea, and annually dispersed their glaciers and icebergs in every direction.

310. In process of time the land was elevated to its present level, *another distribution of sea and land took place, and the* glacial epoch passed away. A new Flora and Fauna suitable to those new conditions were then established in Europe; and these, with the exception of a few that have since become extinct, are the species which now adorn our forests and people our fields. Though we have occasionally used, in the preceding paragraphs, the term "period of extinction," it must not be supposed that the Pleistocene epoch was not characterised by its own peculiar flora and fauna. By "extinction" we merely assert that over large areas of the northern hemisphere the exuberance of mammalian life, so typical of miocene and pliocene eras, ceased to exist, and that, for a long period, arctic and glacial conditions prevailed over these areas, and were consequently accompanied by a scanty and boreal fauna. We see in the arctic character of its marine shells evidence of an independent fauna; and though its clays and gravels have hitherto yielded few remains, we are by no means warranted, from what



Boreal Shells in the Drift of the Clyde.—Smith.
1, Astarte borealis; 2, Leda oblonga; 3, Saxicava rugosa; 4, Pecten islandicus; 5, Natica clausa; 6, Trophon clathratum.

we know of the arctic and antarctic seas of the present day, to

conclude that the boulder epoch, even over northern latitudes, was one of total vital vacuity. Again, we cannot presume that over tropical and sub-tropical latitudes, where the glacial influences did not prevail, there was not both an exuberant and varied flora and fauna; nor, from what we know of existing nature, are we precluded from supposing that many tribes migrated periodically from south to north, as they do now, and left their remains to be entombed in the drift and deposits of the glacial seas. These and other analogous points strongly press themselves *upon the attention of the philosophical inquirer; and not till glacial deposits have been more minutely examined in the* wider expanses of Northern Asia and America, will geology be in a position to offer any positive opinion on the biology of the period.

311. Hitherto we have spoken only of the "Drift" as exhibited in Northern Europe; but similar phenomena are manifested in Canada and the Northern States of America. Again, when we turn to the Antarctic Ocean, analogous appearances present themselves in Terra del Fuego and Patagonia; thus showing that, as at the present day, icebergs and ice-floes are yearly discharged from the Arctic and Antarctic Seas, float towards warmer latitudes, and drop their burdens of sand, mud, and boulders on the sea-bottom; so during the pleistocene epoch the same agencies were at work discharging the same functions, and producing analogous results. And here we may be permitted to remark, that many of the difficulties connected with the origin of the glacial drift have arisen from treating it as an anomalous and mysterious formation. Had geologists, instead of looking to abnormal currents and cataclysms, just treated the "boulder clay" as they did other formations—had they studied more the glacial phenomena of arctic shores, straits, and seas, as well as of mountainous regions situated above the snow-line, and drawn less on their own invention—had they looked to nature as acting through law, and never through capricious disorder—the drift formation, with all its complicated phenomena, had long ere now been an "established fact" of the science, instead of a medley of perverted observations, respecting which scarcely two geologists entertain the same opinion.

["We are still very ignorant of many details of ice action," says Dr Hooker in his Himalayan Journals, "and especially of the origin of many enormous deposits which are not true moraines. Those so conspicuous in the lofty Himalayan valleys, are not less so than those of the Alps: witness that broad valley in which Grindelwald village is situated, and which is covered to an immense depth with an angular detritus, moulded into

hills and valleys; also the whole broad upper Rhine valley, above the village of Munster, and below that of Obergestelen. The action of broad glaciers on gentle slopes is to raise their own beds by the accumulation of gravel which their lower surface carries and pushes forward. I have seen small glaciers thus raised 300 feet; leaving little doubt in my mind that the upper Himalayan valleys were thus choked with deposit 1000 feet thick, of which, indeed, the proofs remain along the flanks of the Yangma valley. The denuding and accumulation effects of ice thus give a contour to mountain valleys, and sculpture their flanks and floors far more rapidly than sea-action or the elements. After a very extensive experience of ice in the Antarctic Ocean, and in mountainous countries, I cannot but conclude that very few of our geologists appreciate the power of ice as a mechanical agent, which can hardly be overestimated, whether as glacier, iceberg, or pack ice heaping shingle along coasts."]

NOTE, RECAPITULATORY AND EXPLANATORY.

312. The Tertiary system, as described in the preceding chapter, embraces all the regular strata and sedimentary accumulations which lie between the Chalk and the close of the Boulder or Drift Formation. Its organic remains are all of recent or *Cainozoic* types, and it may be conveniently arranged into four groups, according to the numerical amount of existing species found imbedded in its strata, thus—

Pleistocene—remains, mostly of existing species.
Pliocene—remains, a majority of existing species.
Miocene—remains, a minority of existing species.
Eocene—remains, few, or the dawn, of existing species.

In their mineral composition and succession these groups present great variety—consisting of clays, sands, marls, calcareous grits, limestones, gypsum, and beds of lignite, with evidences of frequent alternations from marine to fresh-water conditions. On the whole, clays and limestones prevail, and many of the latter are of very peculiar character, as the fresh-water burrstones of Paris, the gypsum or sulphate-of-lime beds of Montmartre, the infusorial tripoli of Bohemia and Virginia, the indusial limestone of Auvergne, the nummulitic limestone of Europe and Asia, and the orbitoidal of America. Separating the older or true tertiaries from the pleistocene or boulder group, it may be said that the former are found, less or more, in almost every country, thought often confined to limited areas, as if originally deposited in inland seas or estuaries. These well-defined deposits are usually termed "basins;" hence the repeated allusions to the

London and Paris basins, in which there are repeated alternations of marine and fresh-water beds, as if at certain stages fresh-water inundations had prevailed in the areas of deposit. The tertiaries of England, France, Switzerland, and Italy, are those that have been most fully investigated, and, though differing in the composition and succession of their strata, are generally regarded as finding their equivalents in those of Britain, which may be briefly grouped as under :—

PLEISTOCENE.	Fossiliferous clays and sands of Clyde, Forth, Holderness, &c. Boulder or drift formation. Preglacial ossiferous gravels, caverns, &c.
PLIOCENE.	Mammaliferous, red, and coralline crag of Suffolk.
MIOCENE.	Leaf-beds of Mull, Antrim lignite, &c. (?)
EOCENE.	Fluvio-marine beds of Isle of Wight. Bagshot sands. London clay. Bognor beds. Plastic clay.

Or placing the British tertiaries in juxtaposition with their supposed foreign equivalents, we have, according to Lyell, the following instructive tabulation :—

	British.	*Foreign.*
PLEISTOCENE or NEWER PLIOCENE.	Glacial drift or boulder formation of Norfolk, of the Clyde, of North Wales. —Norwich Crag.—Cave-deposits of Kirkdale, &c., with bones of extinct and living quadrupeds.	Terrain quaternaire, diluvium. Terrain tertiare superieur. —Glacial drift of Northern Europe; of Northern United States; and Alpine erratics. —Limestone of Girgenti; Australian cave-breccias.
OLDER PLIOCENE.	Red Crag of Suffolk, Coralline Crag of Suffolk.	Sub-Apennine strata.—Hills of Rome, Monte Mario, &c.—Antwerp and Normandy Crag.—Aralo-Caucasian deposits.
MIOCENE.	Marine strata of this age wanting in the British Isles.—Leaf-bed of Mull. Lignite of Antrim (?).	Falurien superieur.—Faluns of Touraine.—Part of Bordeaux beds.—Bolderberg strata in Belgium.—Part of Vienna Basin.—Part of Mollasse in Switzerland.—Sands of James River and Richmond, Virginia, United States.

	British.	*Foreign.*
UPPER EOCENE (*Lower Miocene of many Authors*).	Hempstead beds near Yarmouth, Isle of Wight.	Lower part of Terrain tertiare moyen.—Calcaire Lacustre superieur, and grès de Fontainebleau.—Part of the Lacustrine strata of Auvergne.—Limburg beds, Belgium.—(Rupelian and Tongrian system of Dumont.) Mayence Basin. Part of brown coal of Germany.—Hermsdorf tile-clay, near Berlin.
MIDDLE EOCENE.	1. Bembridge or Binsted Beds, Isle of Wight. 2. Osborne or St Helen's series. 3. Headon Hill sands and Barton clay. 4. Bagshot and Bracklesham beds. 6. Wanting (?).	1. Gypseous series of Montmartre, and Calcaire lacustre superieur. 2 and 3. Calcaire silicieux. 2 and 3. Grès de Beauchamp, or sables moyens.—Laecken beds, Belgium. 4 and 5. Upper and middle Calcaire grossier. 5. Bruxillien or Brussels beds of Dumont. 5. Lower Calcaire grossier, or glauconie grossière. 5. Caiborne beds, Alabama. 5 and 6. Nummulitic formation of Europe, Asia, &c. 6. Soissonnais sands, or Lits coquilliers.
LOWER EOCENE.	1. London clay and Bognor beds. 2. Plastic and mottled clays and sands; Woolwich beds. 3. Thanet sands.	1. Wanting in Paris Basin, occurs at Cassel in French Flanders. 2. Argile Plastique et Lignite. 3. Lower Landenian of Belgium, in part.

313. As already stated, the organic remains of the system belong in greater part to existing genera, and thus among the *plants* we find the leaves, fruits, and seed-vessels of palms, cycads, pines, and, for the first time, of true exogenous timber-trees; while among the *animals* we discover genera of every existing order, with the exception of man. The most characteristic feature of the fauna is perhaps the abundance of gigantic quadrupeds—in European tertiaries, of elephants, mammoths, mastodons, deinotheriums, palæotheriums, rhinoceroses, &c.; in South America, of megatheriums, megalonyxes, glyptodons, &c.; and in Australia, of animals allied to the marsupials of that continent, but of more gigantic proportions. The names given to these animals have reference, in general, to some striking

peculiarity of structure, size, or appearance ; as *mastodon*, from the pap-like crowns of its molar teeth (*mastos*, a nipple, and *odous*, a tooth) ; *glyptodon* (*glyptos*, carved or sculptured), from the curious markings of its teeth ; *megalonyx* (*megalè*, great, and *onyx*, a claw), from its large claws ; *deinotherium* (*deinos*, terrible), terrible wild-beast ; *megatherium*, huge wild-beast ; and the like. In respect of its fossils, the tertiary era presents a remarkable difference compared with those of the chalk, oolite, or coal. During these epochs the plants and animals in every region of the globe presented a greater degree of sameness or identity ; whereas, during the tertiary epoch, geographical distinctions and separations ("biological provinces") like those now existing began to prevail ; hence the difference between the tertiary mammals of Europe and those of South America, which represent its present sloths, ant-eaters, and armadilloes ; and between either of these and that of Australia, which is closely related to existing kangaroos, opossums, wombats, and other kindred marsupials.

314. Whatever the conditions of other regions during the deposition of the tertiary strata, we have evidence from the palms, cycadeæ. huge pachyderms, and monkeys, that in the latitudes now occupied by England and France a warm or subtropical climate prevailed ; and that at the close of the pliocene strata, these conditions were followed by those of an arctic or boreal character, which gave rise to the boulder or drift formation. As a separate group, the middle pleistocene, in its unfossiliferous clays, its huge water-worn boulders, its smoothed and scratched rock-surfaces, and other kindred phenomena, gives evidence of a long period when these latitudes were subjected to arctic conditions, when glaciers covered its hills and islands, and icebergs floated over its waters or ground their way through its firths and straits, smoothing and grooving opposing rock-surfaces, and dropping, as they melted away, their burdens of clay, sand, aud boulders on the deeper sea-bottom.

315. As a system, the TERTIARY still requires much elucidation ; and this the student will readily perceive when he comes to investigate the widespread and heterogeneous deposits attempted to be classed under that category. In his researches he will derive assistance from many published papers and monographs, and in particular from the works of Sir C. Lyell (*Elements and Principles*), who has devoted much attention to the subdivisions and co-ordinations of the strata ; the papers of Prestwich, Trimmer, Morris, E. Forbes, S. Wood, and others,

on the English Tertiaries, in the *Transactions and Journal of the Geological Society;* the memoirs and papers on the French and Continental Tertiaries by D'Archiac, A. Brongniart, Prevost, Deshayes, &c., in the *Bulletin Soc. Geol. de France;* and the papers and reports on the American strata by D. Owen, Hitchcock, Rogers, Locke, &c., in the *Transactions of the Amer. Assoc. of Naturalists.* More especially as regards the fossil remains of the epoch, the student can have ready access to such invaluable authorities as Cuvier's *Ossemens Fossiles*, Agassiz's *Poissons Fossiles*, the classic *Reliquiæ Diluvianæ* of Dr Buckland, the *British Fossil Mammals* of Professor Owen, Von Buch on the *Brown Coal* of Germany, A. Brongniart on *Tertiary Lignites*, in the *Dictionnaire des Sciences Naturelles*, the Notes of Professor Braun on the Œningen lignites, as quoted by Dr Buckland in his *Bridgewater Treatise*, the Monographs of Edwards, Wood, &c., in the *Memoirs of the Palæontographical Society*, and the more popular papers and independent works of the late Dr Mantell. Much valuable information relative to the "drift" and later deposits may be gleaned from such works as Phillips's *Geology of Yorkshire*, Woodward's *Geology of Norfolk*, Lyell's *Travels in North America*, Agassiz's *Etudes sur les Glaciers*, Professor J. Forbes's *Travels in the Alps*, the variously published papers of Mr Smith of Jordanhill, the *Memoirs of the Geological Survey*, and the *Reports of the British Association.* Indeed, few subjects have afforded a more tempting theme for a certain class of *superficial* geologists than the "Northern Drift;" but of the much that has been written and the little that has been observed by these theorists, the student had better remain in ignorance. Such works as Daubeny's *Volcanoes*, Scrope's *Central France*, Hibbert's *Volcanoes of the Rhine*, Von Decken's *Siebengebirges*, and Beudant's *Hungary*, will afford the necessary information respecting the composition and character of the igneous rocks of the period.

XVIII.

POST-TERTIARY OR RECENT SYSTEM:

EMBRACING ALL SUPERFICIAL ACCUMULATIONS AND CHANGES THAT HAVE TAKEN PLACE SINCE THE CLOSE OF THE "DRIFT," OR DURING WHAT IS USUALLY TERMED THE "HUMAN EPOCH."

316. HAVING treated the Boulder-drift as the latest member of the tertiary system, we now proceed to describe, under the term *Post-Tertiary*, all accumulations and deposits formed since the close of that period. However difficult it may be to account for the conditions that gave rise to the "Drift," there can be no doubt regarding the agencies which have been at work ever since in silting up lakes and estuaries, forming peat-mosses and coral-reefs, and laying down beaches of sand and gravel. At the close of the Pleistocene period, the present distribution of sea and land seems to have been established; the land presenting the same surface configuration, and the sea the same coast-line, with the exception of such modifications as have since been produced by the atmospheric, aqueous, and other causes described in Chapter III. At the close of that period the earth also appears to have been peopled by its present flora and fauna, with the exception of some local removals of certain animals, and the general extinction of a few species, whose remains are found imbedded in a partially petrified or *sub-fossil* state in post-tertiary accumulations. We are thus introduced to the existing order of things; and though our observations may extend over a period of many thousand years, yet every phenomenon is fresh and recent compared with those of the epochs already described. With the exception of volcanic lavas, deposits from calcareous and siliceous springs, some consolidated sands and old coral-reefs, we have now no solid strata—the generality of post-tertiary accumulations being clays, silts, sands, gravels, and peat-mosses. As they are scattered indiscriminately over the surface, it is

impossible to treat them in anything like order of superposition; hence the most intelligible mode of presenting them to the beginner, is to arrange them according to their composition, and the causes obviously concerned in their production. Adopting this plan, the principal agencies and their results may be classed as follows:—

FLUVIATILE.	Accumulations of sand, gravel, and alluvial silt in river-valleys. Terraces of gravel, &c., in valleys, marking former water-levels. Deposits of sand, silt, &c., in estuaries, forming "deltas."
LACUSTRINE.	Lacustrine accumulations now in progress. Lacustrine or lake silt filling up ancient lakes. Shell and clay marl formed in ancient lake-basins.
MARINE.	Submarine deposits and accumulations. Marine silt, sand-drift, shingle-beaches, &c. Raised or ancient beaches; submarine forests.
CHEMICAL.	*Calcareous deposits*, as *calc-tuff, travertine*, &c. Siliceous deposits, as siliceous sinter, &c. Saline and sulphurous deposits from hot springs, volcanoes, &c. Bituminous exudations, as pitch-lakes and the like.
IGNEOUS.	Elevations and depressions caused by earthquakes. Displacements produced by volcanic eruptions. Discharges of lava, scoriæ, dust, and other matters.
ORGANIC.	Vegetable—*peat-mosses, jungle-growth, vegetable drift.* Animal—shell-beds, coral-reefs, osseous breccia, &c. Soils—admixtures of vegetable and animal matters.

Or attempting to arrange them chronologically, after Professor Phillips, we have something like the annexed periods:—

RECENT OR HUMAN EPOCH.	1. HISTORICAL PERIOD.—Coins, constructions of civilised man, with remains of domesticated animals, and races extinct in comparatively late periods.	Fens, marshes, and river deposits, of Cambridgeshire, Lincolnshire, Yorkshire, Lancashire, and many parts of Britain and Ireland.
	2. PREHISTORICAL PERIOD. — Rude instruments, marks of uncivilised structures, earliest kinds of burials, remains of red-deer, long-fronted ox, common ox.	Broad gravel-beds deposited in valleys by fresh water—as in the upper Thames, Cherwell, and Clyde valleys — lacustrine deposits, &c.: the level of the land nearly as it is now.
	3. POSTGLACIAL PERIOD IN PART. -- Red-deer, long-fronted ox, Irish elk, Urus priscus, elephant, &c.; forest of modern trees.	Shell-marl under peat, submarine forests, raised beaches, &c., with living *species of shells*, mammoth, &c.: the level of the land variable, but for a time higher than now.

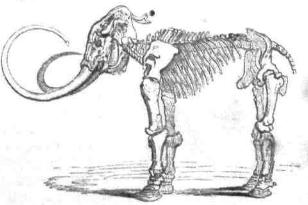
Carefully reviewing the above synopses, and bearing in mind what was stated in last Chapter relative to the difficulty of fixing the age of many superficial deposits, and remembering also what was stated in Chapter III. respecting the causes now modifying the crust of the globe, the student need be presented with little more than a mere indication of these accumulations. From the silt laid down by the floods of yesterday, the soil resulting from the decay of last summer's herbage, or the debris caused by the frosts of the preceding winter, backwards in time to the first-formed alluvium that succeeded the close of the pleistocene epoch, these Superficial Accumulations are everywhere present, demanding the attention of the geologist, if not for their antiquity, at least for their complexity and universality. Enveloping and masking the more ancient strata, they require a distinct and separate survey; and no geological mapping can be considered complete that does not exhibit the extent and nature of these accumulations on one sheet, and the boundaries of the subjacent stratified systems on another.

[The late Dr Fleming, in his *Lithology of Edinburgh*, attempts the following classification of these superficial accumulations—an arrangement which it is well that the student should know, as it may sometimes assist him in unravelling the relations of these very complicated deposits, and that without at all homologating the very extravagant and untenable hypotheses of their author:—"In the Edinburgh basin," he says, "the modern strata seem capable of classification into three groups. The first, or TARAGMITE SERIES (Gr. *taragma*, disturbance), have been formed subsequently to the *dressings*, and, where present, repose upon them. They seem to have been formed when violent aqueous movements were taking place, and probably at a period when the state of our island was widely different from the present. Although extensively distributed in Scotland, they have peculiar characters in different districts. Thus they are dark-coloured on the coal-measures, red on the old red sandstone, and grey in some of the primary districts. The contents are derived from the neighbouring rocks, with occasionally masses transported from a considerable distance, but usually belonging to the river-basin. The second, or AKUMITE SERIES (Gr. *akumos*, tranquil), is chiefly characterised by its laminated clays and sands, and indicates the assorting power of water under circumstances of comparative tranquillity. It contains organic remains, many of which still live in the neighbourhood. It may be looked for wherever brick-kilns have been erected. The PHANERITE SERIES (Gr. *phaneros*, evident) consists of deposits produced by causes in ordinary operation, and respecting the circumstances under which they have been produced little obscurity prevails."]

Fluviatile Accumulations.

317. Under this head are comprehended all accumulations and deposits resulting from the operations of rivers. We have

already seen (pars. 49—55) how streams and rivers cut for themselves channels, glens, and valleys, and transport the eroded materials, in the state of mud, sand, and gravel, to some lower level. During inundations and freshets, some of this debris is spread over the river-plains: in ordinary cases, some of it is deposited in lakes and marshes, should such lie in its course; and in all cases a notable proportion is lodged in estuaries or carried out into the ocean. The natural tendency of rivers being thus to deepen their channels, and spread the eroded matter over the lower levels, all river-valleys will in course of time become dry plains, even though originally consisting of marshes and chains of lakes. Such operations have been going on since the land received its present configuration; and thus we have fluviatile deposits of vast antiquity, as well as accumulations whose origin is but of yesterday. Such alluvial tracts as the "carses," "straths," and "haughs" of Scotland, the "dales," "holmes," and "vales" of England, and, in fact, the flat meadow-lands of most countries, have been formed to a great extent in this way, and, where the rivers are liable to be flooded, are still in process of augmentation. Such accumulations are often of considerable thickness, and consist for the most part of alluvial silt, masses of gravel and shingle, with occasional beds of fine dark-blue unctuous clay, and layers of peat-moss and clay-marl. In many of these river-deposits (Yorkshire, Lancashire, Ireland, &c.) have been found the bones of elephants, rhinoceroses, wild-boars, elks, bears,

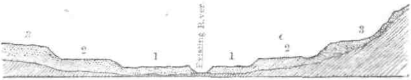


Mammoth.—Elephas primigenius.

hyænas, wolves, beavers, and other animals long since extinct in the British Islands; while accumulations of similar nature in North America have yielded the mastodon, in Northern Asia

and Europe the mammoth and urus, in Australia extinct congeners of the kangaroo, and in New Zealand the bones of the gigantic dinornis and palapteryx.

318. In most of the inland valleys of this and other countries there appear, belting their slopes, long level terraces composed of sand, shingle, and silt. Such terraces give evidence of former water-levels, and point to a time when the valley was occupied by a lake at that height, or when the plain stood at that level, and before the river had worn its channel down to the present depth. *River-terraces* must not be confounded with the raised beaches which fringe many parts of our coasts and estuaries; for, though both are in one sense ancient water-levels, the former may be local and partial, while the latter are general and uniform. Besides, the remains found in the one are of terrestrial or fresh-water origin; in the other they are strictly marine. These terraces have long attracted attention, and point to a time when *many of our fertile valleys were chains of lakes and morasses*, which have been drained and converted into alluvial land by the



River or Valley Terraces, marking former water-levels.

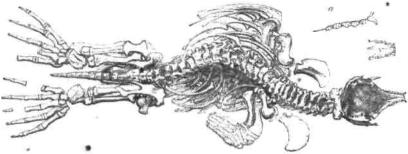
natural deepening of their river-channels. Their remains are generally identical with those of the river-silts noticed in the preceding paragraph—the shells being such as the land helices, and the fresh-water genera, lymnæa, paludina, &c. To the river-drifts and atmospheric debris of this epoch belong also the *auriferous sands, gravels, and clays* of California, the Brazils, Australia, and the Ourals; the *stream-tins* of Cornwall; and other metalliferous accumulations. Many of these date back to a time (chronologically speaking) incalculably remote, and may be in part coeval with the pleistocene gravels and pliocene crags of the Tertiary system; others, again, are evidently the products of existing streams, and may have been transported from their parent hill-cliffs even within the historic era. The process, in fact, is still in operation, and wherever metallic veins are exposed in cliffs and hill-sides, and these cliffs subjected to atmospheric and aqueous waste, there, in the gullies and stream-courses, will

the metallic particles (the "dust," "nuggets," and "pepitas") be deposited, along with the shingle, gravel, and miscellaneous debris.

319. At the mouths or in the estuaries of all existing rivers there have been accumulating, since sea and land received their present configuration, deposits of mud, sand, gravel, and vegetable debris. In course of time these deposits constitute large expanses of low alluvial land, known as "deltas," the most notable instances of which are those of the Rhine and Po in Europe, of the Nile and Niger in Africa, of the Ganges and Chinese rivers in Asia, and of the Mississippi and Amazon in America. Many of these deposits are of vast extent, and, with the exception of what is taking place at the bottom of the ocean (of which we know almost nothing), they are of all modern formations the most important in modifying the crust of the globe. Where a river discharges itself into a non-tidal sea, like the Po into the Gulf of Venice, the delta will be mainly of fluviatile origin; but where the discharge is into a tidal sea, like the Ganges into the Bay of Bengal, the deposit will be partly fluviatile and partly marine. Further, the deltas of tropical rivers subject to periodical inundations are, during the dry season, low flat tracts full of swamps, creeks, and mud-islands (*e.g.* the Niger), which nourish the rankest jungle-growth, herds of gigantic amphibia, shell-beds, and shoals of fishes. On the return of the wet season, many of these plants and animals are buried where they grow, or are swept forward into the ocean. We have thus a complex set of agents—rivers, tides, waves—the drift from inland, the drift from the sea, and the growth of plants and animals *in situ*. All these conjoined render estuary deposits extremely perplexing and irregular in their composition; and though in general terms they may be said to consist of mud, clay, sand, gravel, and vegetable debris, intermingled with organisms of terrestrial, fresh-water, and marine origin, yet scarcely two of them present one feature in common. To this class of deposits belong the "*loess*" or "*lehm*" of the Rhine—a pulverulent yellowish sandy loam, mixed with a little calcareous matter and replete with land and fresh-water shells; the "*rock-sands*" of the Rhone, which are cemented by calcareous infiltrations, and so hard as to furnish an indifferent building-stone; the "*rock-marl*" of the Adriatic deltas; and the "*stone-gravels*" or recent conglomerates that block up the beds of so many of the rivers of Asia Minor.

320. In their fossil contents these estuary deposits must vary according to the countries in which they are situated; the Ganges, for example, entombing in its delta the palms, tree-ferns, gavials, elephants, tigers, and lions of India; the Niger, the palms, the elephant, hippopotamus, rhinoceros, giraffe, camel, and ostrich of Africa; the Amazon, the palms, alligators, llamas, sloths, lemurs, and monkeys peculiar to South America; while the Mississippi floats down the pines, buffaloes, elk, deer, and beavers of the northern continent. Even in their several portions such immense tracts will exhibit many minor differences in their floras and faunas, according to the districts whence the debris may have been borne, and according to the influence exerted by tidal and other marine agencies over the area of deposit. Such minor differences are instructively alluded to by Dr Hooker in his *Himalayan Journals*, when speaking of the delta of the Ganges. "To the geologist," he says, "the Jheels and Sunderbunds are a most instructive region, as, whatever may be the mean elevation of their waters, a permanent depression of 10 or 15 feet would submerge an immense tract which the Ganges, Burrampooter, and Soormah would soon cover with beds of silt and sand. There would be extremely few shells in the beds thus formed, the southern and northern divisions of which would present two very different floras and faunas, and would in all probability be referred by future geologists to widely different epochs. To the north, beds of peat would be formed by grasses; and in other parts, temperate and tropical forms of plants and animals would be preserved in such equally balanced proportions as to confound the palæontologist: with the bones of the long-snouted alligator, Gangetic porpoise, Indian cow, buffalo, rhinoceros, elephant, tiger, deer, boar, and a host of other animals, he would meet with acorns of several species of oak, pine-cones, and magnolia fruits, rose seeds, and cycas nuts, with palm nuts, screw-pines, and other tropical productions. On the other hand, the Sunderbunds portion, though containing also the bones of the tiger, deer, and buffalo, would have none of the Indian cow, rhinoceros, or elephant; there would be different species of porpoise, alligator, and deer, and none of the above-mentioned plants (cycas, oak, pine, magnolia, and rose), which would be replaced by numerous others, all distinct from those of the Jheels, and many of them indicative of salt water, whose proximity (from the rarity of sea-shells) might not otherwise be suspected."

321. As these estuary deposits now vary in their sub-fossil contents, so they must have varied since their commencement, or the time when existing races were restricted to their present biological provinces; and thus, were they well explored, they would afford unerring criteria of any specific changes that may have taken place in the fauna of the current epoch. In regions where there has been little displacement of level, or disturbance of the present distribution of sea and land, these estuary deposits present an unbroken suite from the silts of last tide down to the lowest eocene tertiaries. In all latitudes, however, subjected to the glacial drift, the line of demarcation is by no means obscure; and hence we can judge of any local removals or general extinctions of species that may have taken place since the close of the pleistocene period. In the Clyde, Forth, Humber, Thames, and other British estuaries, we find marine shells of species now rare or extinct in these seas; bones of cetacea, seals, and aquatic



Skeleton of Seal (Phoca vitulina?) from the Brick-clay of Stratheden, Fifeshire, 100 feet above existing sea-level; a. dentition of do.

birds, seldom or never seen in the same latitudes; tusks, grinders, and bones of elephants, hippopotami, elks, urus, bos longifrons, equus fossilis, hyæna, &c., long since extinct in Europe; and in the more superficial beds (at a depth of from 10 to 20 feet) have been discovered canoes, stone hatchets, and other monuments of the prehistoric human epoch. In other countries the organic remains of these estuary deposits present a somewhat similar gradation, from the prehistoric period of man backwards to the times of the mylodon, mammoth, mastodon, and other quadrupeds that lived from the Tertiary into the Current epoch. And here it may be observed that in tropical and sub-tropical latitudes, where the glacial drift does not occur, the geologist may yet find it impossible to draw any sharp line between the earliest

of these estuary deposits and the so-called tertiaries, but be compelled to rank, for example, the *dinornis* muds of New Zealand, the *kangaroo* breccias of Australia, and the *megatherium* silts of South America, along with the older tertiaries, into one unbroken though imperceptibly-varying CAINOZOIC CYCLE.

322. Respecting the geographical extent of river and estuary deposits, our limits preclude any notice of those curious measurements and details, which are given in Lyell's *Principles*, Somerville's *Physical Geography*, and other similar works. We can only extract, as illustrative of their magnitude, the following relative to the delta or alluvial plain of the Mississippi :—" The alluvial plain of the Mississippi begins to be of great width below Cape Girardeau, 50 miles above the junction of the Ohio. At this junction it is about 50 miles broad, south of which it contracts to about 30 miles at Memphis, expands again to 80 miles at the mouth of the White River, and then, after various contractions and expansions, protrudes beyond the general coast-line in the large *delta* about 90 miles in width from north-east to south-west. Mr Forshay estimates the area of the great plain, as above defined, at 31,200 square miles, with a circumference of about 3000 miles, exceeding the area of Ireland. If that part of the plain which lies below, or to the south of the branching off of the highest arm, called the Atchafalaya, be termed the *delta*, it constitutes less than half of the whole, being 14,000 square miles in area. The delta may be said to be bounded on the east, west, and south by the sea ; on the north chiefly by the broad valley-plain, which entirely resembles it in character as in origin. The east and west boundaries of the alluvial region, above the head of the delta, consist of clay cliffs or 'bluffs,' from 50 to 250 feet in height, and which, on the east side of the Mississippi, are very abrupt, and are undermined by the river at many points. They consist, from Baton Rouge in Louisiana, where they commence, as far north as the borders of Kentucky, of geological formations of very modern date, the lowest being Eocene, and the uppermost consisting of loam, with fresh-water and land shells, almost all of existing species. These recent shells are associated with the bones of the mastodon, elephant, mylodon, and other extinct quadrupeds. . . . The deposits of the alluvial plain, and delta proper, consist partly of sand originally formed upon or near the banks of the river and its tributaries; partly of gravel, swept down the main channel, of which the position has continually shifted ; and

partly of fine mud slowly accumulated in the swamps. The farther we descend the river towards its mouth, the finer becomes the texture of the sediment. The whole alluvial formation, from the base of the delta upwards, slopes with a very gentle inclination, rising about 3 inches in a mile from the level of the sea at Balize, to the height of about 200 feet in a distance of 800 miles. That a large portion of this fluviatile deposit, together with the fluvio-marine strata now in progress near the Balize, consists of mud and sand, with much vegetable matter intermixed, may be inferred from the abundance of drift trees floated down every summer, and which form tangled miscellaneous 'rafts,' sometimes, like that of 1816, no less than 10 miles in length, 220 yards wide, and 8 feet deep. . . . Assuming the depth of the delta deposited to be 528 feet (and borings have been made in it to the depth of 600 feet), its area 13,600 square miles, and the solid matter brought down by the river (as calculated by Carpenter and Forshay) to be annually 3,702,758,600 cubic feet, it must have taken 67,000 years for the formation of the whole; and if the alluvial matter of the plain above be 264 feet deep, or half that of the delta proper, it must have required 33,500 more years for its accumulation, even if its area be estimated as only equal to that of the delta, whereas it is in fact larger. Yet the whole period during which the Mississippi has been transporting its earthy burden to the ocean, though perhaps far exceeding 100,000 years, must be insignificant in a geological point of view, since the bluffs or cliffs bounding the great valley, and therefore older in date, and which are from 50 to 250 feet in perpendicular height, consist in great part of loam, containing terrestrial, fluviatile, and lacustrine shells still inhabiting the same country. These fossil shells, occurring in a deposit resembling the *loess* of the Rhine, are associated with the bones of the mastodon, elephant, tapir, mylodon, and other megatheroid animals, also a species of horse, ox, and other mammals, most of them of extinct species. The loam rests at Vicksburg and other places on Eocene or lower tertiary strata, which, in the town, repose on cretaceous rocks."

323. Here, then, in the region of the Mississippi, we have one of those great and gradually varying successions, which unite the eocene strata with the pleistocene Bluffs, and those again with the ancient alluvium of the Plain, up to the last-formed silts of the Delta. By insensible degrees we descend the stream of time from the eocene palæotherium to the pleisto-

cene mastodon, and from the mastodon to the present day, when the silts entomb the remains of buffaloes, bears, wolves, racoons, opossums, otters, minks, beavers, and other creatures now peopling the American continent. As with the delta of the Mississippi, so with all others—making allowance for the region, climate, and biological provinces with which they are connected.

Lacustrine or Lake Deposits.

324. Lacustrine deposits (*lacus*, a lake) are those found either in existing lakes or occupying the sites of lakes now filled up. Lakes are found in every region of the world, and act as settling-pools or filters for the rivers that flow through them. A river on entering a lake may be turbid and muddy, while the water that flows from it is limpid and clear as crystal. The mud or sand settles down as silt, and successive depositions of silt, with intermixtures of vegetable drift and peat-moss and marl, constitute the ordinary composition of lacustrine accumulations. Situated in plains or valleys, a lake serves in general as a basin of reception to several streams and rivers. The mud borne down by these streams settles at their mouths, and forms small deltas, which in process of time are covered with rushes, reeds, sedges, and other marsh plants; new accumulations of sediment push their way into the centre of the lake, and new growths of marsh plants arise. The annual growth and decay of these plants form beds of peat; while fresh-water shells, infusorial animalcules, and calcareous springs, combine to elaborate layers of marl. These agencies, acting incessantly, are gradually shoaling and silting up all lakes; lessening the areas of some, converting others into marshes, and these again into dry alluvial land.

325. Ancient lake-silts or lacustrine deposits are rife in every country; a great proportion of our alluvial valleys are but the sites of marshes and lakes filled up by the processes above described; and though all superficial evidences of the lake be obliterated, the regular manner in which the materials are arranged serves readily to distinguish *lacustrine* from *fluviatile* silt. Respecting the area occupied by lake-deposits, it is impossible to form an accurate estimate, though it is evident the soil of most inland valleys, both in this and in other countries, is in a great measure composed of it. The prairies and savannahs of

North America, the pampas and llanos of South America, and the steppes of Europe and Asia, are regarded by many as partly owing to a general elevation of the land, and as partly the sites of lakes now drained and silted up ; and, considering their relation to existing rivers and valleys of drainage, there is ample foundation for this opinion. Considerable tracts of alluvial land are still in progress of formation along the borders of existing lakes, whose sites, under the double process of silting up and drainage, are evidently destined to become flat verdant plains, like those to which we have alluded. By *drainage* is meant that tendency which rivers, issuing from lakes, have to deepen their channels, and thereby not only lower the level of the parent waters, but also to render them, from their shallowness, more liable to be choked up by aquatic and marsh vegetation.

326. Of the heterogeneous substances—sand, gravel, clay, loam, peat-earth, and marl—composing lacustrine deposits, *marl* is the only one whose formation deserves particular notice. It occurs in many of our British lakes in various states of purity, from a marly clay which will scarcely effervesce with acids, to a shell-marl containing from 80 to 90 per cent of lime. *Marl-clay*, for instance, occurs as a whitish friable clay with an admixture of lime, and sometimes also of magnesian earth ; the term *clay-marl* is applied when the calcareous matter prevails over the clay ; *shell-marl* is almost wholly composed of lime and fresh-water shells, with a trace of clay or other earthy matter ; and, where solidified by the subsequent percolation of calcareous waters, it is known as *rock-marl*. With respect to the origin of these marls there are various opinions, though it is generally admitted that they are derived partly from calcareous springs which enter the lakes, and partly from the shells and secretions of the fresh-water molluscs, the minute crustaceans (cyprides), and the infusorial animalcules, which inhabit them. What tends to confirm this opinion is the fact, that marl-clay and clay-marl are found chiefly among the deposits of ancient or modern lakes situated in limestone districts where calcareous springs abound ; and that shell-marl is often almost wholly composed of the exuviæ of molluscs and infusoriæ, many genera of which are still inhabiting the same lakes and marshes in which the deposit is found. Marl occurs irregularly interstratified with clay-silt, peat-moss, or gravel, and is dug for agricultural purposes in many of the ancient lake-sites and alluvial valleys of Great Britain and Ireland.

327. The organic remains found in lacustrine deposits will

vary, of course, with the region in which they occur, their altitude above the sea even in the same country, the nature of the rocks over which the drainage-waters flow, and other conditions of climate and geography which influence the flora and fauna of a district. In our country the remains are strictly fresh-water and terrestrial—fresh-water shells, as the limnæa, paludina, planorbis, cyclas, mya, &c.; land shells, as the helix; minute crustaceans, as cypris, &c.; diatoms and infusoriæ; marsh plants, as the reed, bulrush, equisetum, &c.; drift or terrestrial plants, as the willow, alder, birch, hazel, oak, pine, &c.; *with bones, horns, and sometimes complete skeletons*, of the great Irish deer, fallow deer, ox, horse, bear, beaver, otter,

Megaceros Hibernicus, or Gigantic Irish Deer.

and other mammalia, some of them long since extinct in the localities where their exuviæ are now found. In many of the *lake-deposits of Britain, Ireland, France, and Belgium*, canoes, stone battle-axes, bone weapons, and other objects of human art, have been discovered, all pointing to the recent period of geology, though historically of vast antiquity, or even far beyond the written records of our race.

Marine Deposits.

328. The marine deposits of the modern epoch naturally divide themselves into three great classes,—those taking place

under the waters of the ocean, as sandbanks and shoals ; those collecting along the sea-margin, as mud-silt, sand-drift, and shingle-beaches ; and those, like ancient beaches, now elevated above the level of the present seas. Respecting the first class of deposits we know very little indeed, few parts of the ocean having been sounded for geological purposes ; and even where sounded, the indications are too obscure to warrant any definite conclusion. So far as dredgings and soundings enable us to decide what is going on under the waters, submarine deposits appear to be extremely varied—here soft slimy mud, there light-coloured clay, with shells ; here shelly sand replete with minute foraminifera and broken corals, there soft chalky mud, arising from the decomposition of corals and accumulations of infusoria ; here black fetid masses of decaying sea-weed, there sandy shoals and gravel-banks ; and over the whole, elevations and depressions as irregular and varied as those of the dry land. Such irregularities of sea-bottom, conjoined with the configuration of sea and land, give rise to numerous currents, and these currents not only distribute the submarine debris, but transport the products of one region to another. The principal ocean-currents are the tides, with all their varied ramifications, the Gulf Stream, and the currents which set in from either pole towards the equator. The tidal currents are perpetually shifting and redistributing the deposits along the sea-bottom ; the Gulf Stream is as regularly transporting tropical products to temperate regions ; and the polar currents carry with them icebergs and ice-floes laden with rocks and gravel, which are dropped on the sea-bottom as the ice melts away in warmer latitudes. All these agents are incessantly at work ; and thus deposits are now accumulating along the bottom of the ocean, which, if raised into dry land, would equal in extent any of the older formations.

329. The bottom of the Mediterranean, for example, has been proved by soundings to consist, in the western portion, of sand and shells ; in the eastern, of impalpable mud and comminuted shells ; and in the Adriatic Gulf, partly of mud and partly of calcareous rock enclosing shells, which are sometimes grouped in families. The German Ocean, according to Mr Stevenson (*Edinburgh Philosophical Journal* for 1820), is deepest on the Norwegian side, where the soundings give 190 fathoms ; but the mean depth of the whole basin may be stated at no more than 31 fathoms. The bed of this sea is traversed by several enormous banks, one of which, occupying a central position, trends from the Firth of

Forth in a north-easterly direction to a distance of 110 miles; others run from Denmark and Jutland upwards of 105 miles to the north-west; while the greatest of all—the Dogger Bank—extends for upwards of 354 miles from north to south. The superficies of these enormous shoals is equal to one-fifth of the whole area of the German Ocean, or about one-third of the extent of England and Scotland. The average height of the banks measures about 78 feet, the upper portion of them consisting of fine and coarse siliceous sand, mixed with comminuted corals and shells. As in the Mediterranean and German seas, so in all other parts of the ocean, agents are at work depositing, however slowly, materials which are destined to form part of the stratified formations of future continents and islands.

330. Marine silt, sand-drift, shingle-beaches, and the like, are the terms usually applied to accumulations which have taken place, or are still in progress, along the present shores of the ocean. Waves and tidal transports are the agents to which these owe their origin; they occur in bays and sheltered recesses, and, as strictly *marine* formations, are not to be confounded with the silt of estuaries and river embouchures. Around the shores of our own island, and, in fact, along the shores of every other country, the tides and waves are wasting away the land in some localities, and transporting the debris to sheltered bays and creeks, there to be laid down as mud-silt, sand, or gravel. This process must have been going forward since sea and land acquired their present distribution, and thus many of these accumulations are both of vast extent and great antiquity—dating back to the epoch of the mammoth and mastodon, whose tusks and grinders are of frequent occurrence among them. As examples of *marine silt*, we may point to the "warp" of the Humber, which occupies an area of more than 300 square miles; to the fens of Lincolnshire, Cambridge, and Huntingdon, which extend to nearly 1000 square miles; to the extensive sands and marshes near Yarmouth; and to the flats of Somerset and Gloucester on the estuary of the Severn. The low plains of Holland and Denmark (more than half the area of Britain) are the direct formation of the German Ocean; in the Levant, Tyre and Sidon, seaports mentioned in Scripture, are now several miles inland; Tehama country on the Red Sea has increased from 3 to 6 miles seaward since the Christian era; and the Isthmus of Suez, which is now about 28 miles broad, is said to have doubled its width since the time of Herodotus (2000 years ago). The organic remains in these silts are chiefly marine, and vary, of course, according to the locality and

latitude in which they occur. In those of Britain we have shells now rather scarce or altogether removed from these seas, the jaw-bones, ribs, and vertebræ of whales, and not unfrequently the tusks, grinders, and bones of the mastodon, mammoth, rhinoceros, and other extinct pachyderms; but whether some of these do actually belong to the period of the silt, or have been derived from the waste of pleistocene cliffs and redeposited in the marine mud, is a subject fairly open to question.

331. Of *sand-drift*, which is first accumulated by the tides and waves, and subsequently blown inland into irregular heights and hollows by the winds (see par. 44), we have many examples in the "links" of Scotland and the "sand-downs" or "dunes" of England. The superficial or blown portion is chiefly composed of fine sand and comminuted shells, with occasional bands of decomposed vegetation or soil; but as we descend (and wells have been sunk to 90 and 120 feet in them) we find stratiform layers of shells, gravel, shingle, and other littoral accumulations. Of those recently-formed sand-drifts, thousands of acres lie waste and worthless (Morayshire, between the Tay and Eden in Fife, between Donegal and Sligo bay in Ireland, in the Bay of Biscay near the Garonne, and along the coasts of Jutland); but of the older and more inland portions, large tracts have been reclaimed, and their distinctive features obliterated by the plough. Many of these sandy tracts are no doubt the result of ordinary silting operations, though some would seem to indicate a gradual uprise of the land from the waters of the ocean. The organic remains in the superficial or drift portion are partly terrestrial and partly marine (the shells of the helix occurring with those of the cockle, mussel, and mactra, the bones of marine birds and fishes with those of land animals, and sea-weeds along with terrestrial plants); but in the deeper strata the remains are chiefly marine, and, from the incohering nature of the deposits, by no means well preserved.

332. Closely connected with sand-drifts, and in fact only differing from them in being the products of more exposed and rocky coasts, are *shingle-beaches*—those accumulations of rounded and water-worn stones which are piled up on certain parts of the coast by the conjoint action of the waves and tides. They occur only along exposed districts, from which the sand and fine debris are swept onwards to the more sheltered recesses. The battering force of the waves during high storms is so powerful, that masses of shingle are often found from 6 to 20 feet above ordinary tide-mark—leaving appearances very perplexing to the geologist who

is unacquainted with the force of waves, the weight which stones lose when *immersed in water, and the curious wedge-like* arrangement which takes place among the individual pebbles. In addition to the forward motion imparted to these beaches by the waves, they are also subjected to the lateral current of the tides; and thus some of them move onward along the coast with so perceptible a motion, that they have been designated *travelling* beaches, like the famous Chesil Bank on the Isle of Portland. Partly owing to the operations of ice, and partly to the peculiar currents of the Arctic Ocean, the shores are there composed for *hundreds of miles of gravel, shingle, and boulders*, which, if consolidated and cemented, would rival the thickest conglomerates of the old red sandstone epoch; and though on our own shores such pebble-beaches are necessarily limited, no one who has witnessed the pebble, or rather boulder ridge of Northam (Devonshire), can doubt the power of existing forces to produce the most gigantic littoral conglomerates.

333. All along the shores of the British Islands, as well as along the shores of every other sea, there exists a level margin, more or less *covered with sand and gravel. This constitutes the existing beach*, or sea-margin; but above it, at various heights, are found, following the bays and recesses of the land, several similar margins or terraces known as "ancient or raised beaches." These give evidence of either elevation of the land or depression of the ocean, and point to times when sea and land stood at these successive levels. Several of these beaches are comparatively recent —*as the Chili upheave of 6 feet* in 1822, and the Ullah Bund at the mouth of the Indus in 1819—and are obviously the results of local earthquakes and volcanic eruptions. Others are of more ancient date, though still coming within the historic period; while most of the higher terraces evidently belong to the dawn of the present geological era. We have several notable examples along our own coasts at heights about 10, 20, 40, and 60 feet above the present sea-level; and sea-shells imbedded even at greater heights, though some of these may be of pleistocene epoch. *Similar beaches are also found along the coast of Greenland* to the height of 500 feet, on that of Norway to the height of 200 feet, on the shores of the Baltic from 20 to 100 feet, in the Bay of Biscay, along the coasts of Spain and Portugal, and conspicuously in many parts of the Mediterranean. In some districts these terraces are covered with sand, shells, and shingle; in other localities a mere shelf or line along a hill-side (like the "parallel roads" of Glen Roy) *is all that bears evidence of the former*

existence of the tides and waves. The remains found in the gravel and sand of these beaches are chiefly shells belonging to *species* now inhabiting the ocean (limpet, periwinkle, cockle, buccinum, &c., in Britain), though a careful examination detects *varieties* apparently extinct. The more elevated terraces, like those of Scotland, Scandinavia, and Greenland, are evidently of great antiquity, and where they occupy wide expanses in ancient firths and bays, are apt to be mistaken by the superficial observer for true diluvial or even tertiary gravels.

["The opportunity which I had to-day (23d March 1855) of comparing the terrace and boulder lines of Mary River and Charlotte Wood Fiord enables me to assert positively the interesting fact of a secular elevation of the crust, commencing as yet at some undetermined point north of 76°, and continuing to the Great Glacier and the high northern latitudes of Grinnell Land. This elevation, as connected with the equally well sustained depression of the Greenland coast south of Kingatook, is in interesting keeping with the same undulating alternation on the Scandinavian side. Certainly there seems to be in the localities of these elevated and depressed areas a systematic compensation. I counted to-day forty-one distinct ledges or shelves of terrace embraced between our water-line and the syenitic ridges through which Mary River forces itself. These shelves, though sometimes merged into each other, presented distinct and recognisable embankments or escarps of elevation. Their surfaces were at a nearly uniform inclination of descent of 5 degrees, and their breadth either 12, 24, 36, or some other multiple of twelve paces. This imposing series of ledges carried you in forty-one gigantic steps to an elevation of 480 feet; and as the first rudiments of these ancient beaches left the granites which had once formed the barrier sea-coast, you could trace the passing from drift-strown rocky barricades to clearly-defined and gracefully-curved shelves of shingle and pebbles. I have studies of these terraced beaches at various points on the northern coast of Greenland. They are more imposing, and on a larger scale than those of Wellington Channel, which are now regarded by geologists as indicative of secular uplift of coast. As these strange structures wound in long spirals around the headlands of the fiords, they reminded me of the parallel roads of Glen Roy—a comparison which I make rather from general resemblance than ascertained analogies of causes."—KANE'S *Arctic Explorations*, vol. ii. pp. 81, 82.]

334. With regard to "submarine forests," which have received considerable attention from local observers, we need only remark, that as raised beaches seem to point to successive elevations of the land, so do these so-called *forests* give evidence of similar depressions. As yet such submerged forests have been found only in limited areas, as in the Firths of Forth, the Eden, and Tay, near the mouth of the Humber in Lincolnshire, in the embouchure of the Mersey, at Bournemouth in Hampshire, and along the low parts of the southern coast of Devonshire. In general, they consist of flat tracts of peat-moss or dark-coloured clay, with numerous stumps and trunks of trees, a few feet under the ordinary sea-level, and only exposed at low tides, or when washed

bare after a storm. The very slight difference existing between the level of these forests and that of ordinary high tide (say from 4 to 8 feet), has suggested the idea that they give no evidence of submergence, but merely point to low woody tracts at one time sheltered from the inroads of the sea by sand-hills and headlands, but laid prostrate and covered by the waves as these sand-hills and barriers were overthrown. Their frequency and their uniformity of level above the existing sea-level would seem to point, however, to some more general cause—in fact, to a period when our island, standing higher above the waters, gave birth to gigantic forests, was subsequently submerged to the depth of 12 or 15 feet, and again upraised to its present level—which is lower to the extent of some 8 or 10 feet than when these forest-growths fringed its bays and estuaries. In whichever way the phenomena may be accounted for, the student has only to remember that secular submergences are quite as possible as secular elevations; and that the half-fossilised oaks, pines, alders, willows, and hazels of these submarine forests are identical with those now flourishing in the same localities, though evidently as old, if not older, than the human occupation of Britain.

Chemical Deposits.

335. Under this head we have classed all deposits arising from calcareous and siliceous springs, all saline incrustations and precipitates, and all bituminous or asphaltic exudations. The most frequent deposits of a calcareous nature are calc-tuff and calc-sinter, stalagmites and stalactites, and travertine. *Calc-tuff*, as the name implies, is an open, porous, and somewhat earthy deposition of carbonate of lime from calcareous springs, and is found in considerable masses or incrustations enclosing fragments of plants, bones, shells, and other organisms. *Calc-sinter*, from the German word *sintern*, to drop, is of similar origin, but more compact and crystalline, and has a concretionary structure, owing to the successive films which are drop by drop added to the mass. *Stalagmites* and *stalactites* (already noticed in par. 61), are often of considerable magnitude in limestone caverns, and are here noticed as frequently enclosing the bones and skeletons of animals found in these caverns. *Travertine* (a corruption of the word Tiburtinus) is another calcareous incrustation, deposited by water holding carbonate of lime in solution. It is abundantly

formed by the river Anio at Tibur, near Rome; at San Vignone in Tuscany, and in other parts of Italy. It collects with great rapidity, and becomes sufficiently hard in course of a few years to form a light durable building-stone. "A hard stratum," says Lyell, "about a foot in thickness, is obtained from the waters of San Filippo in four months; and as the springs are powerful, and almost uniform in the quantity given out, we are at no loss to comprehend the magnitude of the mass which descends the hill, which is a mile and a quarter in length, and the third of a mile in breadth, in some places attaining a thickness of 250 feet. To what length it might have reached it is impossible to conjecture, as it is cut off by a stream which carries the remainder of the calcareous matter to the sea." Travertine is a light, porous, or concretionary rock, well adapted for arches and other structures where weight is objectionable; it is for this reason that it has been used in the construction of the cupola of St Peter's.

336. As with deposits from calcareous, so with deposits from siliceous springs—these forming siliceous tufa and sinter in considerable masses, as at the hot springs or *Geysers* of Iceland, (where it fills fissures 12 and 14 feet in width), the Azores, and other volcanic regions. According to Dr Webster, the hot springs of the Valle das Furnas, in the island of St Michael, rise through volcanic rocks, and precipitate considerable quantities of siliceous sinter. Around the circular basin of the largest spring there are seen alternate layers of coarse sinter mixed with clay, including grasses, ferns, reeds, &c., in different states of petrifaction. Wherever the water has flowed, sinter is found rising 8 or 10 inches above the ordinary level of the stream. The herbage and leaves are more or less incrusted with silex, and exhibit all the successive stages of petrifaction, from the soft state to a complete conversion into stone; but in some instances *alumina* is the mineralising material. Fragments of wood, and one entire bed, from 3 to 5 feet in depth, composed of reeds common to the island, have become wholly silicified; and a breccia is also in act of formation, composed of obsidian, scoriæ, and pumice, cemented by siliceous sinter. Indeed, all our modern breccias—that is, consolidated sands, gravels, shell, coral, and shingle beaches—are cemented and held together by calcareous or siliceous infiltrations; and in this way extensive beds, like the coral-stone of the Pacific, the limestones of Gaudaloupe, and the breccias of Ascension, have been forming from

time immemorial, and contain the petrified remains of shells, fishes, turtles' eggs, bones of sea-birds and land-mammalia, and even skeletons of man himself.

337. In hot countries, incrustations of common salt, nitrate of soda and potash, and other saline compounds, are formed during the dry season in the basins of evaporated lakes, in deserted river-courses, and in shallow creeks of the sea (par. 62). These incrustations go on from year to year, and in course of time acquire considerable thickness, or are overlaid by sedimentary matter, and there exhibit alternations like the older formations. Such deposits are common in the sandy tracts of Africa, in the river-plains of South America, which furnish most of the nitrates of commerce, along the coasts of India, in the salt lakes of Central Asia, the borax lagoons of Northern Italy, and the sal-ammoniac valley-tracts of Persia and Turkestan. Sal-ammoniac, like sulphur, is also a product of modern volcanoes; and both occur in combination with clay and other earthy matter (pars. 61 and 126) in deposits of considerable extent in Sicily, Iceland, West Indies, and other volcanic regions.

338. With respect to springs and exudations of petroleum, asphalt, and the like, it may be remarked that they are too limited and scanty to produce any sensible effect on the bulk of the rocky crust, and are principally of geological importance as throwing light on analogous products of earlier date. Occasionally, like the petroleum springs of the Irawaddi (which yield annually 600,000 hogsheads), the Caspian (which discharge many hundred pounds daily), and the Tigris, they impregnate the soil and gravel for many leagues in their course; like the pitch-lakes of Trinidad, Barbadoes, and Texas, they sometimes constitute pure and independent deposits; while not unfrequently, like those of Bastenne in France, Seyssel, and the Val de Travers in Switzerland, the asphalt is intimately blended with calcareous matter, forming solid irregular masses of which the hills from whence it is quarried consist.

Igneous or Volcanic Accumulations.

339. The effects of igneous action in modifying the crust of the globe have been already adverted to in pars. 63-66 and 125-128, it having been there shown that it acts either as a gradually elevating force, as a displacing and deranging force, or as an accumulating agent by discharges of lava, scoriæ, dust, and

ashes. Whether manifesting itself in quiet upheavals, in earthquakes, or in volcanoes, its geological results are of prime importance; and though the present epoch, as compared with some of the past, be one of rest and tranquillity, yet wide regions of the globe bear witness to extensive modifications even within the history of man. That such must be the case, the student can readily convince himself, by casting his eye over the map of "Volcanic Centres" in Johnston's *Physical Atlas*, and there observing the prevalence of igneous phenomena in almost every region of the world—Europe, Asia, Africa, and America, the islands of the Pacific and Atlantic, the lands within the Arctic and Antarctic Circles, being all alike subjected to the disturbing and modifying influences of igneous action. In par. 128 we detailed the leading lines of centres of active eruption, and from these we can trace an almost unbroken gradation back through the cinders and ashes that entombed Herculaneum and Pompeii eighteen hundred years ago to the tufaceous *trass* of the Rhine, which was coeval with the prehistoric stone period of our race, and from these to the trachytic lavas of Auvergne, which began to be ejected at the dawn of the palæotherian tertiaries, and closed with the epoch of the mastodon, mammoth, and elephant in Europe. As exponents of the recent history of the globe, volcanic products possess comparatively little interest; and it is therefore chiefly to the effects they have produced on the relative level of sea and land, the irregularities of surface they have created, the sudden destruction of life they occasion, and their mere lithological magnitude, that we here briefly direct the student's attention.

340. Volumes might be filled with the records of such changes: our limits only permit of a few instances under each category, beginning with those gradual elevations and depressions which produce, in the long-run, extensive modifications in the flora and fauna of a country. Since the commencement of the present century, the shores of the Baltic have been gradually elevated from 10 to 14 inches above their former level, and are still apparently on the uprise. This movement has been shown by Professor Keilhau to be the continuation of a gradual elevation of the whole of the Scandinavian peninsula, which commenced long anterior to the historic period, and has attained in the south-east of Norway an altitude of nearly 600 feet—an elevation which must have added materially to the rigours of its climate. Extensive flats and terraces along the coasts of Siberia give evidence, according to Von Wrangell, of a recent and gradual uprise of these

regions; and though the shores of south Greenland would appear to be sinking at a slow uniform rate, all to the north of 76° lat. is partaking, according to Dr Kane, of a secular elevation of great extent and altitude—he having counted at Mary River as many as forty-one terraces, making in all a height of 480 feet. As in the northern so in the southern hemisphere, and in no region so impressively as in the southern portion of South America, where Mr Darwin has traced elevations from the deserted beaches of the present century to terraces 400, 600, and 900 feet above the level of the sea. Such uprises may not, however, be gradual but sudden, producing geological results of a very marvellous and instructive description. Thus, by the great Chili earthquake of 1822, an immense tract of ground—not less than 100,000 square miles—was permanently elevated from 6 to 10 feet above its former level; and part of the bottom of the sea remained bare and dry at high water, "with beds of oysters, mussels, and other shells adhering to the rocks on which they grew, the fish being all dead, and exhaling most offensive effluvia." By an earthquake in 1819, a tract—the Ullah Bund—in the delta of the Indus, extending nearly 50 miles in length and 16 in breadth, was upheaved 10 feet; while adjoining districts were depressed, and the features of the delta completely altered.

[Speaking of the gradual elevation of South America, Mr Darwin says: "It may be concluded that the coast on the south-eastern side of the continent, for the space of at least 1180 miles, has been elevated to a height of 100 feet in La Plata, and of 400 feet in southern Patagonia, within the period of existing shells, but not of existing mammifers; that in La Plata the elevation has been very slowly effected; that in Patagonia the movement may have been by considerable starts, but much more probably slow and quiet. In either case there have been long intervening periods of comparative rest during which the sea corroded deeply into the land. That the periods of denudation and elevation were contemporaneous and equable over great spaces of coast, is shown by the equable heights of the plains; and that there have been at least eight periods of denudation [eight escarpments or ancient sea-cliffs]; and that the land up to a height of from 950 to 1200 feet has been similarly modelled and affected." Again, speaking of the western coast, he says: "We have seen that upraised marine remains occur at intervals, and in some parts almost continuously, from lat. 45° 35′ to 12° S. along the shores of the Pacific. This is a distance, in a north and south line, of 2075 geographical miles. Along this great line of coast, besides the organic remains, there are in very many parts, marks of erosion, caves, ancient beaches, sand-dunes, and successive terraces of gravel, all above the present level of the sea. Judging from the upraised shells alone, the elevation in Chiloe has been 350 feet; at Concepcion certainly 625 feet, and by estimation 1000 feet; at Valaparaiso 1300 feet; at Coquimbo, 252 feet: northward of this place shells have not, I believe, been found above 300 feet, and at Lima they were falling into decay at 85 feet. Not only has this amount of elevation taken place within the period of existing mollusca and cirripedes, but their proportional numbers in the existing sea have in most cases remained the same." Further, as

regards the nature of the elevatory action, he remarks: "In many parts of the coast of Chile and Peru there are marks of the action of the sea at successive heights on the land, showing that the elevation has been interrupted by periods of comparative rest in the upward movement, and of denudation in the action of the sea. These are plainest at Chiloe, where, in the height of about 500 feet, there are three escarpments—at Coquimbo, where, in a height of 364 feet there are five—at Guesco, where there are six—at Lima, where, in a height of 250 feet, there are three terraces; and others, as it is asserted, at considerably greater heights. Seeing over how many hundred miles of the coast of Patagonia, and on how many places on the shores of the Pacific, the elevatory process has been interrupted by periods of comparative rest, we may conclude, conjointly with the evidence drawn from other quarters of the world, *that the elevation of the land is generally an intermittent action*."]

341. The above are examples of upheaval on a great scale, and attended with comparatively few convulsions or local displacements. The following are of a different order: In 1692 the town of Port-Royal in Jamaica was visited by an earthquake, when the whole island was frightfully convulsed, and about a thousand acres in the vicinity of the town submerged to the depth of fifty feet, burying the inhabitants, their houses, and the shipping in the harbour. The disasters of the great Lisbon earthquake in 1755, when the greater part of that city was destroyed, and sixty thousand persons perished in the course of a few minutes, have been repeatedly recited; as have also those of Calabria, which lasted nearly four years—from 1783 to the end of 1786—producing fissures, ravines, landslips, falls of the sea-cliff, new lakes, and other changes—changes which, taken in conjunction, afford the geologist one of the finest examples of the complicated alternations which may arise from a single series of subterranean movements, even though of no great violence. In 1743 the town of Guatemala, in Mexico, with all its riches and eight thousand families, was swallowed up, and every vestige of its former existence obliterated; the spot being now indicated by a frightful desert four leagues distant from the present town. So also with the valley of the Mississippi in 1811, which, from the village of New Madrid to the mouth of the Ohio, was convulsed to such a degree as to create lakes, islands, and new water-channels. Such examples might be multiplied indefinitely, even within the limits of the historic period; but enough, we presume, has been quoted to convince the student of the vast amount of change that must have been produced by earthquake shocks and convulsions on the surface of the globe since the commencement of the current epoch.

342. The products of volcanoes, and the effects of volcanic

action, have been sufficiently detailed in pars. 125-129. Th eruptions of Etna and Vesuvius are matters of everyday notor iety; the burying of Herculaneum and Pompeii, a subject o high historic interest; and the trachytic lava-flows of Auvergn —varying from fifteen to thirty miles in length—carry us back t times antecedent to the human race, and yet all within the limit of the current epoch. Sir W. Hamilton reckoned the curren which reached Catania in 1669 to be fourteen miles long and ir some parts six wide; Recupero measured the length of another upon the northern side of Etna, and found it forty miles; whil Spallanzani mentions currents fifteen, twenty, and thirty miles In 1783, the discharges of the Skaptar Jokul, in Iceland, con tinued for nearly three months, producing the most disastrou effects, as well as most extensive geological changes on the fac of the island. The immediate source, and the actual extent o these torrents of lava, have never been actually determined though Pennant speaks of them as covering a surface ninety-fou miles by fifty; but the stream that flowed down the channel of the Skaptar was about fifty miles in length, by twelve or fifteen in its greatest breadth. With regard to its thickness, it wa variable, being as much as five hundred or six hundred feet in the narrow channels, but in the plains rarely more than one hundred, and often not exceeding ten feet. The Hverfisfliot branch of the same eruption was about forty miles in length and seven in its utmost breadth; "and when it is considered," says Captain Forbes, "that all this merely represents that portion which flowed into the inhabited districts, whilst in all probability an equal, if not a greater portion was heaped up at the base of the crater, and in the unknown districts by which it is environed; and if we also take into consideration the pumice, sand, and ashes scattered not only over the whole island, where the greater portion of the pasture was at least temporarily destroyed, but hundreds of miles around, even causing the destruction of the fisheries on the coast—twice the volume of Hecla would hardly represent the matter ejected." Again, "On the 11th of *August* 1855" (we quote the Rev. Mr Coan in *Silliman's American Journal*), "a small point of light was noticed, resembling a brilliant star, on the apex of Mauna Loa [one of the active craters in the Island of Owhyhee], and in full view from Hilo, Byron's Bay. This bright point soon rose and expanded, filling the heavens with a dazzling glare. The eruption progressed with amazing force and rapidity, rolling its wide fiery floods over the mountain's summit down to its base, with appal-

ling fury. Day after day the action increased, filling the air with smoke, which darkened our entire horizon, and desolating immense tracts once clothed with waving forests, and adorned with tropical verdure. This eruption has now been in progress nearly ten months, and still the awful furnace is in blast. The amount of matter disgorged is enormous: the main stream is nearly seventy miles long (including its windings), from one to five miles wide, and varying from ten to several hundred feet in depth." We quote these as instances of hundreds that might be adduced to show the extent of discharges from existing volcanoes. Whether as lava, pumice, scoriæ, dust, hot mud, or ashes, volcanic products, both on land and under the ocean, are materially adding to the structure of the rocky crust, just as in former epochs similar functions were performed by the granites, porphyries, basalts, traps, and trap-tuffs of the mineralogist. *Nor is it to the mere accumulation of igneous rock-matter in* certain localities that the student must look for the chief results of volcanic effort. As in former epochs, so even now we have lines and axes of volcanic elevation; and chains of hills, like those pointed out by Von Tschudi in Peru, and by Darwin in the Pacific, have risen almost within the scope of the human era. Palæontologically, volcanic tufas and lavas enclose terrestrial, fresh-water, and marine remains; and these must vary in character, not only in point of time, but geographically, as the case may be, in connection with such volcanic centres as those of Italy, the Indian Archipelago, or the islands in the Pacific.

Organic Accumulations.

343. *Organic accumulations*, as depending on the agencies described in pars. 56-59, consist either of vegetable or of animal remains, or of an intimate admixture of both. The most important of those resulting from vegetable growth are peat-mosses, jungle-swamps, drift-rafts, and submerged forests. *Peat*, which is a product of cold or temperate regions, arises chiefly from the annual growth and decay of marsh plants—reeds, rushes, equisetums, grasses, sphagnums, confervæ, and the like, being the main contributors to the mass, which in process of time becomes crowned and augmented by the presence of heath and other shrubby vegetation. Peat-moss has a tendency to accumulate in all swamps and hollows; and wherever stagnant water prevails, there it increases, filling up lakes, choking up river-

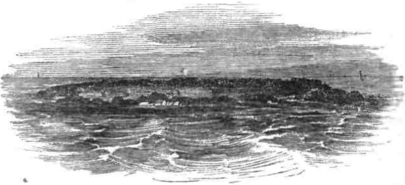
courses, entombing fallen forests, and spreading over every surface having moisture sufficient to cherish its growth. It occupies considerable areas in Scotland and England, though rapidly disappearing before drainage and the plough; but it still covers a wide extent of surface in Ireland. It is found largely in the Netherlands, in Russia and Finland, in North America, and in insular positions, as Shetland, Orkney, and the Falkland Islands. Of the absolute surface occupied by peat, we have no accurate estimate; but some idea of the geological importance of the formation may be formed from the fact, that one of the mosses on the Shannon is fifty miles long, and from two to three in breadth, while the great marsh of Montoire, near the mouth of the Loire, is not less than fifty leagues in circumference. Some of the Scottish mosses have been dug for fuel to the depth of twenty feet, and many in Ireland and Holland are reckoned at twice that thickness. It occurs in all stages of consolidation, from the loose fibrous "turf" of the previous summer, to the compact lignite-looking "peat" formed thousands of years ago. It has been attempted to classify peat as *turf*, *hill-peat*, *bog-peat*, &c., according to the situations in which it occurs, or according to its texture and composition as *fibrous*, *papyraceous*, *earthy*, and *piciform*; but seeing that the whole is so irregularly and intimately blended, such distinctions are of little practical value. Besides the peculiar plants which constitute the mass, peat-mosses contain the trunks of the oak, pine, birch, alder, hazel, willow, and other trees, together with their seeds, fruits, and cones—apparently the wrecks of forests entangled and destroyed by the accumulation of the swampy peat, prostrated by storms, or felled by the hand of man. And, what is deserving of special notice, the trunks of many of those trees are of most gigantic dimensions, in districts where now the same species struggle on for a stunted and dwarfish existence. Bones and horns of the Irish elk, stag, ox, and other animals, are found in most of our British mosses, with occasional remains of human art, as canoes, stone axes, querns, flint arrow-heads, &c., of the British stone-period; Roman weapons and coins that date to the first invasion of the island by the legions of Cæsar; and not unfrequently the skeleton of man himself. Some of these fossils are comparatively modern; others point to a period apparently coeval with the dawn of the human race.

344. As with peat-mosses in temperate latitudes, so with the jungle-growth of tropical deltas, as those of the Niger, Ganges, and Amazon; so with the cypress-swamps of the United States,

and so also with the pine-rafts and vegetable debris borne down by such rivers as the Mackenzie, Mississippi, &c., and entombed in the lakes that lie in their course, or amid the silt of their estuaries. All are adding to the solid structure of the globe, and forming beds, small it may be in comparison, but still analogous to the lignites of the tertiary, and the coals of the carboniferous era. Speaking of the Canadian lakes and rivers, many of which annually receive vast quantities of drift timber, Dr Richardson remarks: "As the trees retain their roots, which are often loaded with earth and stones, they readily sink, especially when water-soaked; and, accumulating in the eddies, form shoals, which ultimately augment into islands. A thicket of small willows covers the new-formed islands as soon as they appear above water, and their fibrous roots serve to bind the whole firmly together. Sections of these islands are annually made by the river, assisted by the frost; and it is interesting to study the diversity of appearances they present, according to their different ages. The trunks of the trees gradually decay until they are converted into a blackish-brown substance resembling peat, but which still retains more or less the structure of the wood; and layers of this often alternate with layers of clay and sand, the whole being penetrated, to the depth of four or five yards, by the long fibrous roots of the willows. A deposition of this kind, with the aid of a little infiltration of bituminous matter, would produce an excellent imitation of coal. It was in the rivers only that we could observe sections of these deposits; but the same operation goes on on a much more magnificent scale in the lakes. A shoal of many miles in extent is formed on the south side of Athabasca Lake, by the drift timber and vegetable debris brought down by the Elk River; and the Slave Lake itself must in process of time be filled up by the matters daily conveyed into it by Slave River."

345. Accumulations resulting from animal agency are universal and varied; but those of any appreciable magnitude are chiefly coral-reefs, shell-beds, and infusorial deposits. The nature and growth of the coral zoophyte has been already alluded to in par. 59, and we need here only observe the extent of its distribution in the Pacific, Indian, and Southern Oceans. Viewing a *coral-reef* as essentially composed of coral structure, with intermixtures of drift-coral, shells, sand, and other marine debris, we find such masses studding the Pacific on both sides of the equator, to the thirtieth degree of latitude; abounding in the southern part of the Indian Ocean; trending for hundreds

of miles along the north-east coast of Australia; and occurring less or more plentifully in the Persian, Arabian, Red, and Mediterranean Seas. In the Pacific, where volcanic agency is actively upheaving and submerging, coral-reefs are found forming low circular islands, enclosing lagoons (*atolls*, or *lagoon-*



Whitsunday Island, or Atoll.

islands), surrounding islands of igneous and other origin (*fringing*, or *shore-rees*), crowning others already upheaved (*coral ledges*), or stretching along shore in surf-beaten ridges (*the true barrier or encircling reef*) of many leagues in length, and from twenty to more than two hundred feet in thickness. Regarding them as mainly composed of coral, and knowing that the zoophytes can only add on an average little more than a foot to the structure during a century, many of these reefs must have been commenced before the dawn of the present epoch; and looking upon them as consisting essentially of carbonate of lime, we have calcareous accumulations rivalling in magnitude the limestones of the secondary formations. Captain Flinders describes the great reef which follows the line of the north-east coast of New Holland as more than 1000 miles in length, in course of which there is one continued portion, exceeding 350 miles, without a break or passage through it. The thickness of the mass is variable—in some instances less than twenty feet, and in others more than a hundred.

346. The composition and construction of coral-reefs (which have necessarily received a vast amount of minute attention from our scientific voyagers), though effected chiefly by lime-secreting zoophytes, seem owing, in some measure, to the promiscuous aggregation of marine debris. As produced by the zoophyte, coral is almost a pure carbonate of lime, soft and

porous at first, but gradually becoming so hard and compact as to be used in the South Sea Islands for building. During its formation, however, it encloses shells, fragments of drift-coral, sea-weeds, sponges, star-fishes, sea-urchins, drift-wood, and the like ; and these being cemented in one mass by the growth of new coral, the drift of coral-sand, and the infiltration of carbonate of lime from decomposed coral, the rock presents a brecciated appearance extremely analogous to some older limestones. Again, the sediment deposited in the lagoons and sheltered water-channels, and which arises from the decomposition and trituration of the coral, and from the raspings and droppings of the animals which bore into or browse upon it, produces when dried and consolidated a substance scarcely distinguishable from some earthy varieties of chalk. Further, where reefs have been upheaved by subterranean agency, as the strata of fossil coral on the hills of Tahiti, or enveloped in volcanic tufas, as in the Isle of France, where a bed ten feet thick occurs between two lava currents, the "coral-stone" has a sparry crystalline aspect—thus presenting the geologist with almost every gradation of limestone, from the soft chalky mass of yesterday's secretion to the compact texture of saccharoid marble.

["The fragments of coral," says Mr Darwin, when describing Keeling atoll, "which are occasionally cast on the 'flat,' are, during gales of unusual violence, swept together on the beach, where the waves each day at high water tend to remove and gradually wear them down ; but the lower fragments, having become firmly cemented together by the percolation of calcareous matter, resist the daily tides longer, and hence project as a ledge. The cemented mass is generally of a white colour, but in some few parts reddish from ferruginous matter: it is very hard, and is sonorous under the hammer: it is obscurely divided by seams, dipping at a small angle seaward: it consists of fragments of the corals which grow on the outer margin, some quite, and others partially rounded, some small, and others between two and three feet across ; and of masses of previously-formed conglomerate, torn up, rounded, and re-cemented ; or it consists of calcareous sandstone, entirely composed of rounded particles, generally almost blended together, of shells, corals, the spines of echini, and other such organic bodies. Rocks of this latter kind occur on many shores where there are no coral-reefs. The structure of the coral in the conglomerate has generally been much obscured by the infiltration of spathose calcareous matter ; and I collected a very interesting series, beginning with fragments of unaltered coral, and ending with others where it was impossible to discover with the naked eye any trace of organic structure."]

347. *Shell-beds*, like those formed by the oyster, cockle, mussel, and other gregarious molluscs, are found in the seas and estuaries of every region, often spread over areas of considerable extent, and of several feet in thickness. Dead shells are also accumulated on certain coasts in vast quantities ; and shell-sand, entirely composed of comminuted shells, is drifted for leagues

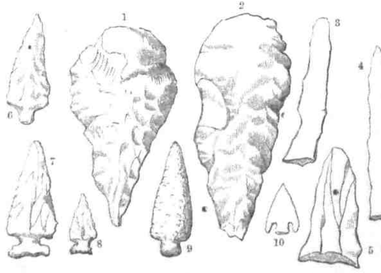
along the shores of every existing sea. In fact, when we consider the myriads of testacea that throng the waters of the ocean, the rapidity with which they propagate their kind, and the indestructible nature of their shells, we are compelled to admit their accumulations to a place in the present epoch as important as that which they held in any of the earlier eras. Occasionally the drifted shells and shell-sand of existing coasts are cemented into a compact durable breccia by the infiltration of calcareous matter resulting from their own decomposition; in many of our raised beaches, shell-beds several feet in thickness constitute a prominent feature; and could we lay bare the bottom of many seas and estuaries, shell-beds entombed *in situ* would be discovered rivalling in magnitude the shelly limestones of the stratified systems. As the range of the testacea, both in point of depth and geographical latitude, is now pretty well known to the zoologist, the shell-beds become important indices not only to any change of climate, but to any elevation or depression of sea-bottom that may have taken place in the regions where they now occur.

348. In treating of the chalk and tertiary strata, we saw what an important part had been played in the formation of certain beds by infusorial animalcules and minute foraminifera; and so far as the researches of microscopists have gone, it would appear that the same minute agencies are still at work in the silt of our lakes and estuaries, and in the shoals of our seas. What the eye regards as mere mud and clay, is found, under the lens of the microscope, to consist of countless myriads of infusorial shields, or the shells of foraminifera—a discovery whose limits will be further extended as the microscope becomes, as it soon must be, the inseparable companion of the geological inquirer. It has been ascertained by Ehrenberg, for example, that infusorial accumulations are now choking up the harbour of Wismar in the Baltic; that similar formations are effecting changes in the bed of the Nile at Dongola in Nubia, and in the Elbe at Cuxhaven; and that many of our ochraceous bog-iron ores consist chiefly of the siliceo-ferruginous shields of these minute and myriad animalcules. The *berg-mähl* (mountain-meal) of Iceland and Lapland, the "edible clay" of Brazil, and the "white earth" of the American Indians, are evidently of the same nature—and these are spread over many miles in extent and several feet in thickness. According to Pictet, 6000 shells of foraminifera have been counted in an ounce of sand from the shores of the Adriatic; D'Orbigny found 3,840,000 in the same quantity from the shores

of the Antilles; and every cast of the sounding-lead, alike in the Atlantic, Pacific, and Australian seas, brought up thousands to the naturalists of the United States Exploring Expedition. Nay, it has been shown, by still more recent soundings, that calcareous marls, rich in *polythalamia*, *polycistins*, *diatoms*, and *spongiolites*, form the bed of the Gulf Stream through its whole course, as far as yet examined, and that the same organically-formed marls occur in vast extent in the Gulf of Mexico. Indeed, from its western margin almost completely across the Atlantic (we quote Prof. Bailey), the bed of the Gulf Stream is marked by calcareous organisms,—thus indicating a formation in progress as gigantic as any that Zoology has yet revealed, and yet dependent upon forces apparently the most trivial and insignificant in nature.

349. Although coral-reefs, shell-beds, and infusorial deposits are the only accumulations of any magnitude arising from animal agency, there are still some masses arising from the excretiæ and exuviæ of the larger animals that have a curious interest both in a lithological and palæontological point of view. Thus the *guano* of the Pacific and other tropical islets, so valuable as a manure, consists mainly of the droppings of countless sea-fowl, intermingled with their skeletons and eggs, the decayed bodies and bones of fishes, seals, sea-lions, and other marine creatures. Considering the immense thickness of some guano-deposits, and their necessarily slow accumulation, the lower beds must be of vast antiquity—carrying us back to the very verge of the current era. So also of the *osite* or *Sombrero guano*, which constitutes the whole of the West India island of that name. This islet, nearly three miles in length, more than half a mile in width, and from twenty to thirty feet high, is entirely composed of the altered bones of turtles and other marine vertebrata, which must have accumulated for ages on some shoal, been cemented together into a mass, and subsequently elevated above the level of the ocean. The "Bone-bed" or shoal about twenty miles eastward of the Faröe Islands is a similar deposit, still in course of accumulation, consisting for the most part of bones of fishes, seals, and other creatures that throng these northern waters. Sands and gravels containing masses of drift bones, such as the tusks and grinders of the mammoth and elephant, the bones and teeth of the rhinoceros, hippopotamus, horse, bear, &c., and the horns and bones of the elk, stag, and wild ox, are common in the valleys of Britain, in the river-plains of North America, and in the gravel cliffs of Siberia and the polar seas. These *ossiferous*

sands and *gravels* are clearly later than the glacial drift, and if not in some instances the retransported material of the preglacial ossiferous gravels (par. 303), are referable to the period of our earliest raised beaches, and to the time when the sea and land received their present configuration. To this curious series of accumulations belong the mastodons found in the bog-marls of North America, the mammoths of Siberia and the islands in the polar seas, the dinornis and other gigantic wingless birds of New Zealand, the epiornis of Madagascar, and the elephants, rhinoceroses, aurochs, Irish deer, wild boars, and beavers of the valley-deposits of Europe. And it is just in this palpable approach to existing nature that we begin to detect the earliest traces of the human species. *First, and far back among the river-silts* and peat-bogs and cave-earths, we discover his rude stone implements



1, 2, From valley of Somme ; 3, 4, 5, England ; 6, 7, 8, Canada : 9, 10, Scandinavia.

and weapons, his tree canoes, and the embers of the fires which he alone of all animals can either kindle or sustain. Side by side with these remains, occasionally lie bones of the mammoth, *rhinoceros, and Irish deer (the valley of the Somme,* Holxne in Suffolk, &c.) ; but whether these may not have been washed up, drifted, and reassorted from earlier deposits, is a question not always easily determinable. However the question may be ultimately answered, one thing is certain, that just as the *mammoths* and *mastodons* drop away, and the *horse, ox,* goat, and sheep begin to spread over Europe in increasing numbers, so the traces of primeval man become more frequent and

unmistakable. In all likelihood—nay, it is all but certain, that over the plains and through the forests of the Old World man hunted the Irish deer and speared the mammoth, just as at a later period, and in the same region, he lassoed the wild horse and impounded the urus and buffalo. With regard to this subject, however—viz., the first appearance of man—much unnecessary discussion has taken place, and a great deal of uneasy tenderness been displayed. Like other events in geological history, we have at present no means of assigning to it a definite date in years and centuries. The time is merely relative, and all that science can safely do is to ascribe it to an early, though not to the very earliest, stages of the pleistocene epoch. The human skeletons found in some Continental caverns and osseous breccias, in the river-silts of South America, in the peat-bogs of our own island, and in the tufaceous limestone or coral-conglomerate of Guadaloupe (with the exception, perhaps, of those found imbedded in the volcanic breccia of Mount St Denis in central France—a breccia containing bones of elephant, rhinoceros, Irish deer, &c.), are, comparatively speaking, but of yesterday, and date back at the utmost but a few thousand years.

350. The deposits described in the preceding paragraphs are either of vegetable or of animal origin; but there is an intimate admixture of both in the *soil* or superficial covering of the earth. Strictly speaking, soil is an admixture of decomposed vegetable and animal matter—the decay of plants, and the droppings and exuviæ of animals. Though generally containing a large proportion of earthy ingredients, its dark loamy aspect renders it readily separable from the "subsoil" of sand, clay, or gravel, that lies beneath. It is of universal occurrence, no portion of the earth's crust being uncovered with it, unless, perhaps, the newly deposited debris on the sea-shore, the shifting sands of the desert, or the snow-clad mountain-top. In some places it barely covers the flinty rock, in others it is several feet in thickness and evidently of great antiquity; and everywhere it is annually on the increase, partly from the decomposition of plants and animals, partly from animal excretiæ, and partly from new additions of wind and water-borne inorganic particles. It is curious to observe in sections of some undisturbed soils the various layers of vegetable humus, lines of land-shells, fragments of pottery, and other objects of human art, and these again succeeded by lower layers of roots and vegetable mould, traces of early culture, and, deeper than all, fragments of bone, charred wood, stray coins, stone hatchets, and flint arrow-heads—the whole, though only a few

feet of "superficial soil," carrying us backward through the lapse, it may be, of more than twenty centuries. It is thus that these superficial coverings of soil—of "ruin and rubbish"—insensibly interweave the chronology of the historian with that of the geologist, leading the one from historic to prehistoric times, and the other from prehistoric traces of the human race downwards through fossiliferous strata whose antiquity ceases to be registered by years, and can be only dimly indicated by the lapse of biological cycles and systems.

NOTE, RECAPITULATORY AND EXPLANATORY.

351. *In the preceding chapter we have briefly indicated the* nature and extent of the various accumulations that have taken place, and are still taking place, all over the surface of the globe since the close of the Boulder formation. Of course it is always difficult, and often impossible, to fix precisely the limits of a geological formation, inasmuch as the close in one region may not be simultaneous with its termination in another; and in the case of the Glacial Drift there is this additional difficulty, that as the land rose from the waters, part of the drift was re-transported, again deposited, and ultimately elevated in the closest proximity with the clays and boulders from whence it was derived. Again, while the Glacial Drift forms a sort of guiding-post in northern and southern latitudes, its absence in tropical and in sub-tropical countries increases the difficulty of drawing there the line of severance between Pleistocene and Recent accumulations. Lithologically, therefore, all that can be done is to embrace under one great category all the superficial formations that have taken place since the ocean and continents received the outlines (or nearly so) of their present configuration; or, speaking palæontologically, since the establishment of existing biological provinces. Adopting this plan, we have classed these accumulations under the head POST-TERTIARY or RECENT, and subdivided them into the following groups, according to the agents more immediately concerned in their aggregation:—

FLUVIATILE ...River accumulations and estuary deposits.
LACUSTRINE...Lake-silt and marl-beds.
MARINE........Marine-silt, sand-drift, shingle-beaches, &c.
CHEMICAL.....Calcareous, siliceous, and saline aggregations.
IGNEOUS........Discharges of lava, &c., earthquake displacements, &c.
ORGANIC ....Peat-mosses, shell-beds, coral-reefs, infusorial accumulations, &c.

As all these agencies are incessantly at work, some of the preceding accumulations are still in progress, others are comparatively recent, and some, again, of vast extent and unknown antiquity. Indeed, when estuary deposits, alluvium in valleys, lake-silts, peat-mosses, sand-drifts, and coral-reefs, are taken in the aggregate, they assume a geological importance not at all inferior, as far as amount is concerned, to any of the older stratified formations.

352. Lithologically, the formation of these superficial accumulations is patent and apparent; and thus, while of high interest in themselves, they acquire additional importance from furnishing us with a key, as it were, to the more obscure and complicated phenomena of earlier epochs. There is no difficulty, for instance, with the formation of such mechanical aggregates as fluviatile, lacustrine, and marine mud-silts, with sand-drifts, gravel, and shingle-beaches; none with the chemical aggregation of calc-tuff, siliceous sinter, or saline incrustations, though sometimes we may doubt as to the sources whence the materials are derived; and there is nothing obscure (when rightly studied and apart from preconceived theories) in the growth of shell-beds, coral-reefs, and infusorial masses. The lithofaction of such organic masses as shell-marl, coral-reefs, and peat-beds, and the internal changes they assume under pressure, infiltration of mineral waters, and other chemical affinities, present some interesting questions, but no insuperable difficulty to the chemist and physicist; and the main difficulties connected with the rocks of the period are those that attach to the products of volcanoes already adverted to in the Recapitulation of Chapter VII. In fact, the whole Petralogy of the period—however much we may marvel at the extent of coral-reefs, the innumerable organisms in infusorial deposits, the antiquity of peat-mosses, or the prevalence of volcanic phenomena—is a thing taking place beneath and around us, and the student who fails to comprehend its nature and origin need scarcely attempt the solution of earlier formations.

353. The Palæontology of the period might be left to the botanist and zoologist, as all but synonymous with the botany and zoology of existing nature, were it not for many *local removals*, as the elephant, rhinoceros, wild-boar, elk, bear, wolf, beaver, &c., from our own islands, and several *general extinctions*, as the mammoth, rytina, dinornis, æpiornis, dodo, solitaire, and Philip's Island parrot. The cosmical conditions of our planet forbid any cessation of progress; and thus while its inorganic materials are being worn down, shifted, and reconstructed into new ar-

rangements, its vitality must also undergo corresponding modifications, redistributions, and it may be extinctions. Adopting this view the Post-Tertiary may be conveniently grouped into the following sub-periods :—

POST-TERTIARY.

- HISTORIC.—Accumulations and changes within the range of history—containing coins, implements and weapons of metal, or objects of art, that can be referred to some definite period of human chronology.
- PREHISTORIC.—Accumulations and deposits imbedding stone implements and weapons, and other evidences of man anterior to any definite period in history.
- MAMMOTHIAN.—Accumulations containing the remains of the mammoth, &c., with which we have yet no certain evidence that man was contemporary.

Through these stages—historic, prehistoric, and mammothian—we are led insensibly into the Tertiary system; and there in many of the superficial beds the remains of the Mammoth are associated with those of the earlier and more cosmopolitan Mastodon.

Industrial Products.

354. In an economic point of view, the materials of the Post-Tertiary system are of vast and universal value. From its *clays* we obtain an unfailing supply for pottery, bricks, tiles, drain-pipes, and other fictile purposes; its purer *sands* supply the glass-maker with silica, the builder with setting for his mortar, and the metal-smelter with material for his moulds; its *gravels* and *shingle* are used in every country for road-making; while many of the same fluviatile sands and gravels are the main repositories of drift-gold, as in California, Brazil, Australia, and the Oural; of stream-tin, as in Cornwall; and of gems and precious stones, as in India and other countries. The *marls* of the system have been long used in agriculture, as have also the *shell-sands* of many shores, and the *warp* or tidal silt of certain estuaries. *Peat*, when dug in rectangular blocks and dried in the sun, or compressed by hydraulic pressure, constitutes in many districts the principal fuel, not only for domestic use, but for burning lime, heating corn and malt kilns, and when charred by a smothered combustion, makes an excellent coke for the smelting of iron and similar purposes. Attempts have also been made in this country to extract from its mass tannin, naphtha, paraffine, and other chemical products; and the value of decomposed peat is well known to the farmer and gardener. The *saline incrustations* of common salt, nitrates of soda and potash, borax, sal-ammoniac, and the like, have been early made use of by man;

and recently the nitrate of soda has become an extensive importation from South America for manurial purposes. The *Bitumens*—naphtha, petroleum, and asphalt—have been long known and used in the arts, manufactures, and medicine. Asphalt (*a*, not, and *sphallo*, I slip) was anciently used as a cement, and also in embalming; and now it is extensively employed in the manufacture of roofing, linings for cisterns, foot-pavements, &c. Distilled naphtha is largely used as a solvent for caoutchouc, and occasionally as a substitute for oil in lamps, &c. The industrial applications of the volcanic products—lava, pumice, puozzolana, trass, sulphur, &c.—have been already adverted to in par. 129, to which the student may again refer. The value of certain kinds of coral for ornamental purposes is well known; and the massive reef furnishes one of the most accessible and purest of limestones.

355. On such an obvious and universal subject as the Superficial Accumulations, we have necessarily many authors, some of whom may be consulted with advantage. For instance, the *Principles of Geology*, by Sir Charles Lyell, is quite a storehouse of facts relative to current geological events; so also is De La Beche's *Geological Observer;* and much information may be drawn from Mrs Somerville's *Physical Geography*. On the subject of Coral Reefs, we have the authority of Darwin in his valuable work *On the Structure and Distribution of Coral Reefs*, of Dana in the *Report on the Geology of the American Exploring Expedition*, of Stutchbury in the *West of England Journal*, of Beechy in his *Voyage to the Pacific*, and of many other recent voyagers. On Peat Moss, the *Treatise* of De Luc and the *Essays* of the Rev. Mr Rennie may be consulted with advantage; and the standard work of Dr Daubeny *On Volcanoes* contains most of the facts connected with the subject, or supplies the name of the author who has written on the igneous phenomena of different localities. Palæontologically, Professor Owen's *Fossil Mammalia of Britain*, the *Ossemens Fossiles* of Cuvier, the *Palæontologies* of Pictet and D'Orbigny, and the *Reliquiæ Diluvianæ* of Dr Buckland, will supply the main features of a fauna which differs little, except in the extinction of a few genera, from the fauna of existing fields and forests. The *Antiquités Celtiques et Antediluviennes* of M. Boucher de Perthes, and the papers of Mr Prestwich, Dr Falconer, Sir Charles Lyell, and others in the *Geological Journal*, will furnish all the reliable information yet known respecting the flint implements and other remains of human art that have been recently discovered in the valley of the Somme, in the alluvia of England, in the bone-caves of Sicily, and other European localities.

Having treated the stratified systems in detail, but chiefly as they are developed in Britain, it may now be instructive to present in tabular arrangement what seem to be the contemporary or equivalent deposits in other regions. Without such a correlation it will be impossible for the student to read with appreciation the papers and treatises of Continental and American geologists, while a knowledge of these comparisons will greatly facilitate his comprehension of foreign geology should it ever be his fortune to travel in the countries to which they refer :—

CONTEMPORARY OR EQUIVALENT DEPOSITS.

I. POST-TERTIARY SYSTEM.

	British.	*Foreign.*
HISTORICAL.	Peat of Great Britain and Ireland, with human remains, &c. Fens, marshes, and river-deposits, with ancient *canoes, implements, &c.* Lake-silts, fresh-water marls, &c., with canoes, metal implements, remains of domesticated animals, &c. Accumulations of sand-drift, shore-caves, and beach-deposits, considerably beyond the reach of existing tides.	Terrain quaternaire of French authors in part. — Modern portion of Deltas of Rhine, Nile, Ganges, Mississippi, &c.—Marine strata enclosing temple of Serapis at Puzzuoli. — Fresh-water strata enclosing temple in Cashmere.—Tundras of Siberia; Tarai or Jungle soil of India; Cypress swamps, &c., of America.—Modern part of coral-reefs of Red Sea and Pacific.—Travertine of Italy; calcareous tufa of Guadaloupe; and Lavas of Vesuvius and Etna, overspreading objects of human art, &c.
PREHISTORICAL.	Peat-moss, Lake-silts, and other alluvia, with tree-canoes and rude stone implements. Alluvia and river-deposits, with remains of Irish deer, wild oxen, mammoth, and other extinct mammals. Cave-deposits in part, with bones of extinct mammals, stone implements, and fragments of charred wood.	Terrain quaternaire of French authors in part. — Upper Alluvia of Tigris and Euphrates.—River-silt of Upper Egypt in part.—Upper portion of cave deposits of Mediterranean and Southern Europe, with stone implements and charred wood.—Gravels of the Somme with flint implements and bones of extinct mammals.—Plain of Holland in part; and much of the river-alluvia of America.

	British.	*Foreign.*
POST-GLACIAL.	Shell-marl under peat, and submarine forests of modern trees. Raised beaches at various heights, with species of shells more boreal than those of existing seas. Ancient alluvia and gravel of most of our carses, straths, dales, and holmes — the "Brick Clay" of many authors. Contains remains of seals, whales, &c.; and of extinct land mammals, as mammoth, rhinoceros, urus, &c. Cave-deposits in part, with bones of extinct and living carnivora and herbivora — ursus, hyæna, megaceros, rhinoceros, hippopotamus, &c. No human remains.	Loess of the Rhine, with recent fresh-water shells and mammoth bones.—Volcanic tufa of Ischia, with living species of marine shells, and without human remains or works of art.—Newer boulder formation in Sweden. — Bluffs of the Mississippi. — Driftwood and mammoth gravel of the Arctic seas.—Tchornozem or black-earth of the Aralo-Caspian plain.—Auriferous Drift, in part, of the Uralian, Australian, and Californian gold-fields.

II. TERTIARY SYSTEM.

PLEISTOCENE or NEWER PLIOCENE.	Glacial drift or boulder formation of Norfolk, of the Clyde, of North Wales —the "Boulder Clay" of many authors. — Norwich Crag.—Cave-deposits of Kirkdale, &c., with bones of extinct and living quadrupeds.	Terrain quaternaire, diluvium. Terrain tertiare supérieur. —Glacial drift of Northern Europe; of Northern United States; and Alpine erratics. — Limestone of Girgenti Kunkur of India (?); Australian cave-breccias.
OLDER PLIOCENE.	Red Crag of Suffolk, Coralline Crag of Suffolk.	Sub-Apennine strata.—Hills of Rome, Monte Mario, &c.—Antwerp and Normandy Crag.—Aralo-Caucasian deposits, older part.—Pampas Formation of South America, &c.—Lignitiferous strata of the Northern Prairies.
MIOCENE.	Marine strata of this age wanting in the British Isles.—Leaf-bed of Mull. Lignite of Antrim (?).	Falurien supérieur. — Faluns of Touraine.—Part of Bordeaux beds. — Bolderberg strata in Belgium.—Part of Vienna Basin.—Part of Mollasse in Switzerland.—Sands of James River and Richmond, Virginia. — Greensands and marls of Maryland, United States.

	British.	Foreign.
UPPER EOCENE (*Lower Miocene of many Authors*).	Hempstead beds near Yarmouth, Isle of Wight.	Lower part of Terrain tertiare moyen.—Calcaire lacustre supérieur, and grès de *Fontainebleau*.—Part of the Lacustrine strata of Auvergne.—Limburg beds, Belgium.—(Rupelian and Tongrian system of Dumont.) Mayence Basin. Part of *brown coal of Germany*.—Hermsdorf tile-clay, near Berlin.
MIDDLE EOCENE.	1. Bembridge or Binsted Beds, Isle of Wight. 2. Osborne or St Helens series. 3. Headon Series. 4. Headon Hill sands and Barton clay. 5. Bagshot and Bracklesham Beds. 6. Wanting (?).	1. Gypseous series of Montmartre, and Calcaire lacustre *supérieur*. 2 and 3. Calcaire siliçieux. 2 and 3. Grès de Beauchamp, or sables moyens.—Laecken beds, Belgium. 4 and 5. Upper and Middle Calcaire *grossier*. 5. Bruxillien or Brussels Beds of Dumont. 5. Lower Calcaire grossier, or glauconie grossière. 5. Caiborne beds, Alabama. 5 and 6. Nummulitic formation of Europe, Asia, &c. 6. Soissonnais Sands, or Lits Coquilliers.
LOWER EOCENE.	1. London Clay and Bognor Beds. 2. Plastic and mottled clays and sands; Woolwich Beds. 3. Thanet Sands.	1. Wanting in Paris Basin, occurs at Cassel in French Flanders.—Litnaestones and Clays of the Carolinas (?). 2. Argile Plastique et Lignite. 3. Lower Landenian of Belgium, in part.

III. CRETACEOUS SYSTEM.

MAESTRICHT BEDS.	Wanting in England.	Danien of D'Orbigny. Calcaire pisolitique, Paris. Maestricht Beds. Coralline limestone of Faxoe in Denmark.
UPPER WHITE CHALK.	White Chalk, with flints.	Senonien of D'Orbigny. Obere Kreide and Upper Quader-sandstein of the Germans. La Scaglia of the Italians. Yellow Limestone and Greensand of New Jersey, in part.

	British.	*Foreign.*
LOWER WHITE CHALK.	Chalk without flints. Chalk Marl.	Turonian of D'Orbigny. Calcaire à hippurites, Pyrenées. Upper Pläner Kalk of Saxony. Yellow Limestone and Greensand of New Jersey, in part. Coal-yielding strata of Vancouver Island and Rocky Mountains.
UPPER GREENSAND.	Loose sand, with bright green grains. Forestone of Merstham, in Surrey. Marly stone, with chert, Isle of Wight.	Cénomanen of D'Orbigny. Grès Vert supérieur. Craie Chloritée. Lower Quader-sandstein of the Germans.
GAULT.	Dark-blue Marl, Kent. Folkestone Marl. Black Down Beds (sandstone and chert), Devonshire.	Albien of D'Orbigny. Glauconie Crayeuse. Lower Pläner Kalk of Saxony.
LOWER GREENSAND.	Greensand of Kent and Sussex. Limestone (Kentish Rag). Sands and Clay, with calcareous concretions and chert, Atherfield, Isle of Wight. Speeton Clay, Yorkshire.	Grès Vert inférieur. Neocomien supérieur. Aptien of D'Orbigny. Hils Conglomerat of Germany. Hils-thon of Brunswick.
WEALDEN.	Clay, with occasional bands of limestone and sandstone; Weald of Kent, Surrey, and Sussex. Sand, with calcareous grit and clay; Hastings, Cuckfield, Sussex.	Neocomien inférieur. Formation Waldienne. Wälderformation of North Germany.

IV. OOLITIC OR JURASSIC SYSTEM.

UPPER OOLITE.	1. Purbeck Beds. 2. Portland Stone and Sand. 3. Kimmeridge Clay.	1. Serpuliten Kalk and Wälderformation of N. Germany, in part.—2. Portlandien of D'Orbigny.—3. Kimmeridgien of D'Orbigny.—Calcaire à gryphées virgules, of Thirria.—Argiles de Honfleur of De Beaumont.
MIDDLE OOLITE.	1. Calcareous Grit. 2. Coral Rag. 3. Oxford Clay. 4. Kelloway Rock.	1 and 2. Corallien of Beudant and D'Orbigny.—Calcaire à Nerinnées of Thurmann.—3. Oxfordien supérieur.—4. Oxfordien inférieur or Callovien of D'Orbigny.

	British.	*Foreign.*
LOWER OOLITE.	1. Cornbrash and Forest Marble. 2. Great (or Bath) Oolite and Stonesfield Slates. 3. Fuller's Earth, Bath. 4. Calcareous Freestone and Yellow Sands (Inferior Oolite).	1 and 2. Bathonien; Grand Oolithe; Calcaire de Caen. 3 and 4. Oolithe inférieur; Oolithe ferrugineux of Normandy; Oolithe de Bayeux; Bajocien of D'Orbingy.
LIAS.	1. Upper Lias. 2. Marlstone. 3. Lower Lias.	1. Toarcien of D'Orbigny. 2. Lias Moyen; Liasien of D'Orbigny. 3. Calcaire à gryphée arquée; Sinemurien of D'Orbigny; Coal-field of Richmond, Virginia (?); and Coal-fields of India and Indian Archipelago (?).

V. TRIASSIC SYSTEM.

UPPER.	Bone-bed of Axmouth; Saliferous and Gypseous Shales and Sandstones of Cheshire; Reptiliferous Sandstones of Elgin (?).	Saliferien of D'Orbigny; Marnes irisées of the French; Keuper of the Germans.
MIDDLE.	Wanting in England.	Conchylien of D'Orbigny, in part; Calcaire à Cératites of Cordier; Muschelkalk of Germany.
LOWER.	Red and White Sandstones and Quartzose Conglomerates of Lancashire and Cheshire.	Bunter Sandstein of the Germans; Grès bigarré of the French; Conchylien of D'Orbigny, in part; Red Sandstones of Connecticut, U. S.; Reptiliferous Sandstones of Southern Africa and Bengal.

VI. PERMIAN SYSTEM.

MAGNESIAN LIMESTONE.	1. Laminated and Concretionary Limestones of York and Durham. 2. Brecciated Limestone do. 3. Fossiliferous Limestone. 4. Compact Limestone, do. 5. Marl-slate of Durham.	1. Stinkstein of Thuringia. 2. Rauchwackè do. 3. Dolomit or Upper Zechstein. 4. Zechstein proper. 5. *Mergel or Kupfer schiefer.*
RED SANDSTONE.	Red Sandstones, Grits, and Marls; Dolomitic Conglomerate of Bristol, Exeter, Annandale, &c.	Rothliegendes of Thuringia. Permian of Russia. Grès des Vosges of French. Red Sandstones of Chatham, North Carolina, U. S.

VII. CARBONIFEROUS SYSTEM.

	British.	*Foreign.*
UPPER.	1. Upper or True Coal-Measures.	1. Coal-fields of the United States.
MIDDLE.	1. Millstone Grit of England. 2. Mountain or Carboniferous Limestone.	2. Calcaire Carbonifère of the French.—Bergkalk or Kohlenkalk of the Germans.—Pentremite Limestone, U.S.
LOWER.	1. Lower Coal-measures and "Calciferous Sandstones" of Scotland.—Lower Limestone, Shale, Mendips. — Carboniferous Slates of Ireland.	1. Kiesel Schiefer and Jüngere Grauwackè of the Germans. Gypseous Beds and Encrinital Limestones of Nova Scotia.—Cypridina Schiefer of Nassau, Saxony, &c.

VIII. DEVONIAN OR OLD RED SANDSTONE.

UPPER.	1. Yellow Sandstones of Dura Den, Fifeshire; and of Kilkenny, Ireland. 2. White and chocolate-coloured Sandstones and Grits of Berwick and Roxburgh.	1. Upper Devonians of Russia; Cypridina Schiefer of Germany, in part. 2. Catskill Group, U.S.
MIDDLE.	1. Red Sandstones and Marls of Perth, Forfar, Hereford, &c. 2. Upper and Middle Schists and Limestones of Devonshire. 3. Micaceous and Bituminous Flags of Caithness. 4. Great Pebbly Conglomerate of Scotland.	1. Eifel Limestone; and Upper and Middle Devonians of Russia, in part. 2. and 3. Middle Devonians of Russia, in part; Chemung, Genessee, and Hamilton Groups, North America.
LOWER.	1. Lower Devonian of North Devon. 2. Grey Flagstones of Perth and Forfar; Tilestones of Hereford, in part.	1. Spirifer Sandstone and Slate. 2. Russian Devonian, lower part; and Onondago and Oriskany Groups, North America.

IX. SILURIAN SYSTEM.

UPPER.	1. Upper Ludlow Rocks; Lesmahago Tilestones. 2. Aymestry Limestone. 3. Lower Ludlow. 4. Wenlock Limestone and Shale. 5. Llandovery Rocks.	1-5. Upper stages of Bohemian Basin; E to H of Barrande. 1-3. Pentamerus, Delthyris, and Onondago Groups, New York.—4. Schoharie Coralline Limestone.—5. Medina Sandstone.

	British.	Foreign.
LOWER.	1. Caradoc Sandstone. 2. Bala Beds. 3. Llandeilo and Lingula Flags. 4. Longmynd or "Bottom Rocks."	1 and 3. Lower stages of Bohemian Basin; C and D Barrande. — 4. Primordial zone of Barrande; Slates of Angers, France.—1-4. From Oneida Conglomerates to Potsdam Sandstone inclusive.

X. CAMBRIAN SYSTEM.

UPPER.	Fossiliferous Schists of Wicklow; Schists and Slates of North Wales.	Alum Schists of Sweden; lowest fossiliferous rocks of Wisconsin and Minnesota.
LOWER.	Lower Grits and Schists of Dumfries; and Grits, Schists, and Conglomerates of North-Western Highlands.	Huronian Sandstones and Chloritic and Gneissose Schists.

XIX.

GENERAL REVIEW OF THE STRATIFIED SYSTEMS—THEORETICAL DEDUCTIONS.

356. THE object of Geology, we have stated, is to discover the constitution and unfold the history of our globe. What are the materials of which this earth is composed; what are the causes that have led to their formation and present arrangement; what the nature of the vegetable and animal remains they entomb, as compared with those now peopling its land and waters; what evidence do these afford of past change and progress; and, combining the sum of such evidence, what is the history of our earth, tracing back, through all its manifold phases, from the current hour to the earliest moment of which we have record in the rock-formations we investigate? This is Geology—this the wide field of labour; these the numerous and complicated problems—this the attractive though arduous task that lies before the geological inquirer. In tracing the history of our own race, the archæologist exhumes buried cities and catacombs, collects objects of human art, deciphers monumental inscriptions, and notes every vestige of the successive tribes that have peopled any given locality; so in Geology, the truthful inquirer examines every stratum, exhumes every fragment of plant or animal he detects, and notes every impress of the past, be it a footprint, the ripple-mark of a passing current, or the pittings of a rain-drop. Every fact, however small in itself, augments the amount of evidence; and thus it is that mere chips and fragments, which the foot of the ignorant would spurn from its path, and the road-maker consider sorry material for his purpose, are in the eye of science invested with as high an interest as the obelisks of Egypt, or the sculptures of Nineveh. The one carries the human chronologer, at most only over the checkered lapse of a few thousand years, the other bears the geologist back immeasurably into the past; and if historians are disagreed as to time and incidents so recent,

what marvel need it be that geologists are not yet at one respecting events and epochs, compared with which the most distant dates of man are but as the moments of yesterday? And after all, uniformity in geological belief is much more general than is commonly supposed; and just for this reason, that we are dealing with great cosmical events, the results of laws and operations that are now acting, have acted, and will continue to act, in the same uniform manner, while the present constitution of Nature remains.

Uniformity of Natural Operations.

357. The agencies that now operate on and modify the surface of the globe—that scoop out valleys and wear down hills; that fill up lakes and estuaries and seas; that submerge the dry land and elevate the sea-bottom into new islands; that rend the rocky crust and throw up new mountain-chains; and that influence the character and distribution of plants and animals—are the same in kind, though differing it may be in degree, as those that have operated in all time past. The layers of mud and sand and gravel now deposited in our lakes and estuaries and along the sea-bottom, and gradually solidifying into stone before our eyes, are the same in kind with the shales and sandstones and conglomerates that compose the rocky strata of the globe; the marls of our lakes, the shell-beds of our estuaries, and the coral-reefs of existing seas, year after year increasing and hardening, belong to the same series of materials, and in process of time will be undistinguishable from the chalks and limestones and marbles we quarry; the peat-mosses, the jungle-growth, and the vegetable drift that have grown and collected within the history of man, are but continuations of the same formative power that gave rise to the lignites and coals of the miner; the molten lavas of Ætna and Vesuvius, and the cinders and ashes of Hecla, are but repetitions of the same materials which now compose the basalts and greenstones and trap-tuffs of the hills around us; while the corals and shells and fishes, the fragments of plants and the skeletons of quadrupeds, now imbedded in the mud of our lakes and estuaries and seas, will one day or other be converted into stone, and tell as marvellous a tale as the fossils we now exhume with such interest and admiration. Without this uniformity in the great operations of nature, the history of the PAST would be

an uncertainty and delusion. We can only read the past as connected with the present; and premise of the future from what is now going on around us.

358. And here the student is met with this difficulty at the outset, namely, that many writers on the science are in the habit of treating geological phenomena as the results of "cataclysms," and "revolutions," and "aberrant forces," without seeking for their solution in the fixed and ordinary operations of nature. In one sense, such occurrences as the submergence of the Ullah Bund in India, the Lisbon earthquake, the discharges of Hecla, and the like, are in their local results cataclysmal and revolutionary; but, after all, they are merely exponents of established forces in nature, which have operated less or more through all time, and seem as necessary for the conservation of a habitable terraqueous globe, as the heat of the sun or the daily rotation of the earth on its axis. In cosmical operations we may not always be able to trace the continuous line of law by which they are regulated; but in such instances it is certainly much more philosophical to lay the defect at the door of our own inability to trace, than to ascribe it to irregularity and disorder in nature. And after all, there are really very few phenomena in the crust of the earth that cannot be accounted for by existing causes. The boulder clay, with its huge water-worn blocks, meets with its analogues in arctic and glacial regions; the most massive conglomerates are matched by existing shingle-beaches; the granites and basalts of our hills have their types in active volcanoes and volcanic productions; limestones in living coral-reefs; and coal-beds in the peat-mosses, jungle-growths, and vegetable drifts of the current epoch. If the operations of the past seem, in some cases, to have been conducted on a more gigantic scale, or with greater rapidity, than those of the present day, this too may be readily accounted for by different arrangements of sea and land, and by concentrating, as it were, the power of any set of forces for a continuous period in one direction, and within the limits of one locality. Until we ascertain the power of existing causes under every possible phase of arrangement, it is alike premature and unphilosophical to have recourse to abnormal conditions, and the student of geology abandons the right path of investigation the moment he appeals to other causes than those now operating above, beneath, and around him. Nor does it at all involve the idea of "revolutions" and "cataclysms" to believe, for example, the earth to have gradually cooled down from an incandescent state to its

present temperature, to admit the periodical passage of the solar system through hotter and colder regions, or to rely on certain great successional and progressional movements in nature for the solution of some of our problems. There is only this to be observed, that our reasonings can never be founded securely on any other basis than that of fact, and that where science cannot arrive at a solution through the powers and processes of existing nature, it will be little aided by having recourse to the possible and plausible. Again, where the FORCE seems unequal to the result, the student should never lose sight of the element TIME—an element to which we can set no bounds in the past, any more than we know of its limit in the future.

359. It will be seen from this hasty indication, that there are two great schools of geological causation—the one ascribing every result to the ordinary operations of nature combined with the element of unlimited time; the other appealing to agents that operated during the earlier epochs of the world with greater intensity, and also, for the most part, over wider areas. The former belief is certainly more in accordance with the spirit of right philosophy, though it must be confessed that many problems in geology seem to find their solution only through the admission of the latter hypothesis. As far as existing evidence goes, palæontology has established the fact of progressional gradations in the vital economy of the globe, and it may be that more exact investigation may yet establish analogous gradations among its purely physical phenomena. There is nothing unphilosophical, we have already said, in the hypotheses (and many facts seem to favour the belief) that the earth has gradually cooled down from a state of molten incandescence; that volcanic activity was consequently more intense and general during earlier epochs than now; that during the successive stages of refrigeration the earth enjoyed a higher surface-temperature; that this higher temperature was accompanied by tropical phases of vegetation and vitality; and that on this single idea of progression may rest the solution of many of the most important problems in Geology. But then we must again warn the student, that such hypotheses, however plausible, cannot possibly be accepted as "true and sufficient causes" till Geology has secured more extensive evidence, and learned to put all her facts through a more rigid course of probation. So far as human observation extends, we have no sufficient evidence, for example, of the gradual refrigeration of the globe, of the secular contraction of its mass, of its

passage through hotter or colder regions of space, of any secular change in its axis of rotation, of any retarding medium affecting its orbit round the sun, of any cometic influence deranging the quiet steady movement of its waters, or, in fact, any evidence of one of those great revolutionary causes that are occasionally appealed to by the geological theorist. Nor, on the other hand, do the existing operations of nature give the least shadow of support to the belief in alternating periods of activity and violence, of cessation and repose—a belief at one time in favour among a certain class of geologists, and not yet altogether discarded from the popular lecture-room. So far as the present state of our knowledge enables us to decide (and by this alone should the student ever seek to be guided), the operations of nature appear to be fixed and uniform within certain ascertainable limits, and beyond these there seems to lie some great law of *cosmical progression*, clearly indicated in the geological history of the past, and ever rising up before us as a matter of faith, but standing as yet beyond the grasp of exact scientific demonstration.

State of Geological Inquiry.

360. Having made himself familiar with the operations now taking place on the surface of the globe, the geologist proceeds to examine the rock-materials of which it is composed, to describe their composition and relative positions, to investigate the remains of plants and animals they contain, to ascertain the areas they occupy, so as to indicate the conditions and appearance of the world during former epochs, and ultimately to arrive at a knowledge of the peculiar Floras and Faunas that have successively peopled its surface. For this purpose, he descends into the stratified or accessible crust, and there he finds tide-rippled sandstones that must have formerly spread out as sandy shores; conglomerates that formed pebbly beaches; shales that were the muddy clays of former lakes and estuaries; limestones that once were living coral-reefs; and coal-beds composed of the remains of a bygone vegetation. Here, also, we discover imbedded corals and shells and fishes that must have lived in the ocean; reptiles that thronged shallow bays and estuaries; huge mammalia that browsed on river-plains; and plants, some that flourished in the swampy jungle, and others that reared their trunks in the tropical forest. Of all this, though mineralised and converted into

stone, there is the clearest and most abundant evidence; and could the geologist map out the mutations of sea and land from the present moment to the earliest time of which he has traces in the rocky crust—could he restore the forms of the fossil plants and animals found in the successive strata—could he indicate their habits and the climate and conditions under which they grew and lived—Geology would have accomplished its task, and have done for the past aspects of the world what geography and natural history are now doing, and have done, for its present features. As yet the outline of such a history is faint and imperfect; but when we reflect how difficult it is to trace back the history of the human race even for a few thousand years, which, *compared with the epochs of Geology, are but as the hours of* yesterday, the marvel becomes, not that the outline of geological history is so faint, but that its facts are so numerous and well ascertained. The band, moreover, of ardent and qualified investigators is yearly on the increase; new facts are daily coming in from every quarter of the globe; and the time, it is hoped, is not far distant when the geologist shall be enabled to read the history of the world before man, with as much, if not with greater, certainty than we can now read the phases of human history itself, as displayed in the successive developments of Ninevites and Egyptians, of Greeks and Romans, of medieval Goths and modern Anglo-Saxons.

361. Satisfactory, however, as has been the progress of geology during the last fifty years—hopeful as are its prospects, it cannot be denied, and the student cannot be too deeply impressed with the fact, that the great tendency of many investigators is to rush at once into generalisation and law without the necessary data; while others too timorously avoid generalisation, and bewilder themselves in a maze of minute and unimportant distinctions. We have on the one hand your world-maker and developist confidently constructing the world, and peopling it to his own satisfaction, upon the slenderest basis of fact, but the broadest of unsupported assumption; and on the other hand, your microscopic fact-observer and species-maker, unable apparently to comprehend the connection of what he observes—dignifying with the name of "science" a wilderness of little discoveries and unimportant distinctions. The one, shirking the labour of observation, would construct a world without the necessary material; the other, unable to comprehend the value of law, plumes himself on his tact in technalising, it may be, the tail of a trilobite. All honour to the patient

investigator of facts, for without facts we can never have legitimate deductions—all reverence for the mind that honestly strives to arrive at the true expression of a law, for without law nature's facts appear but an unintelligible medley, without plan or arrangement. What we would guard the student against, is the proneness to rush into extremes—the tendency that has recently been exhibited in quarters from which better things might have been expected—to dignify mere observation with the name of geological science ; and the craving for notoriety that impels to "theories of the universe," which do violence to fact and retard the progress of right investigation. As mere hypothesis can never constitute Law, so a mere collection of facts, however numerous, can never be regarded as the ultimate object and scope of a science. True geology has a different aim before it ; its cultivators a different function to perform. And the interesting problems it has already solved—the expanded view it has given us of creation—and the wondrous variety and complexity of extinct life it has revealed, take rank already among the established beliefs of human reason, as the proudest triumphs of correct observation and inductive philosophy.

Systematic Arrangements.

362. The exponents of geological history, we have said, are the rocky strata of the globe ; and these, after diligent research in many and distant regions, have been arranged into groups and systems, each set occurring above another in point of time being spread over certain areas, marked by some peculiarity of composition, and characterised by the remains of certain plants and animals not found in any other series of strata. In fine, each group and system is the exponent of a certain period of time, and of the operations that took place during that period in the area where the stratified group or system occurs. In arranging these groups, the earlier geologists were guided more by mineral than by fossil distinctions ; hence such a tabulation as the following :—

Alluvium, Diluvium, London clay,	TERTIARY.
Chalk, Oolite, New red sandstone, Coal-measures, Old red sandstone,	SECONDARY.

Greywackè,	TRANSITION.
Mica schist, and gneiss, Granite and porphyry,	PRIMARY.

Such an arrangement tells little more than the prevailing composition of the rocks and their order of succession. From their structure and texture, their relative thickness, their repeated laminations, and so forth, we might form some idea of the *physical agencies concerned in their aggregation, and* of the length of time required for their deposition. This, however, would be all; and not till we had examined the remains of plants and animals imbedded in the strata, could we tell whether these had been deposited in lakes, or estuaries, or seas; could we say whether the climate of the region had been arctic, temperate, or tropical; could we depict the successive phases of *the vegetable and animal life that peopled the globe; or could* we pronounce on the various mutations which that vitality had undergone during the long progression of ages, so clearly indicated by the systems of the geologist. The moment, however, that the palæontology was grafted on the lithology of the stratified systems, the science assumed a new interest, and geologists became more anxious to trace the successive phases of vitality, *than to be curious about mere mineral and physical distinctions.* Proceeding upon this idea, the various rocks, from the sands and gravels scattered on the surface down to the deepest-seated strata, may be arranged in groups and systems and life-periods as follows :—

Groups.	*Systems.*	*Periods.*	
Deposits in progress, Recent,	POST-TERTIARY.	CAINOZOIC.	NEOZOIC CYCLE.
Pleistocene, Pliocene, Miocene, Eocene,	TERTIARY.		
Chalk, Greensand,	CRETACEOUS.	MESOZOIC.	
Wealden, Oolite, Lias,	OOLITIC.		
Saliferous marls, Muschelkalk, Upper new red sandstone,	TRIASSIC.		
Magnesian limestone, Lower new red sandstone,	PERMIAN.		

Groups.	*Systems.*	*Periods.*	
Coal-measures,	CARBONIFEROUS.	PALÆOZOIC.	PALÆOZOIC CYCLE.
Millstone grit,			
Mountain limestone,			
Lower coal-measures,			
Yellow sandstones,	DEVONIAN.		
Red sandstones and conglomerates,			
Devonian limestones and schists,			
Fissile flags and tile-stones,			
Upper Silurian,	SILURIAN.		
Lower Silurian,			
Cambrian (?),			
Clay slate,	METAMORPHIC.	HYPOZOIC.	
Mica schist,			
Gneiss and granitoid schists,			

363. In each of these groups and systems, as was seen while treating them in detail, there are certain plants and animals not occurring in any other group or system—the range of difference being less between the Groups than the Systems, and being still more marked in the Periods and Cycles. Proceeding upon this fact, it has been attempted to exhibit the progress of the world by vital gradations alone,—disregarding altogether the mineral and mechanical conditions of the rocks in which they occur. There is an evident error in this, however, as the object of the geologist is to unfold not merely the development of life, but the past physical and geographical phases of the globe; and this, not alone in still serenity of sea and land, and peopled with certain races of plants and animals, but in a state of busy activity and change, and subjected to all those ceaseless agencies that degrade and reconstruct the mineral material of which it is composed. It is better, therefore, for the young geologist to accustom himself to associate the rocks with the fossils they imbed—to combine, for example, the silurian strata with their trilobites and lingulæ and cystideæ, rather than speak of a "trilobitian epoch," to the subordination of other races, which may be quite as characteristic of the system, though not occurring in the same numerical abundance.

364. It is needless, we presume, again to warn the student against the error of attaching to these "groups" and "systems" and "periods" a value that does not properly belong to them. It is true, for example, that the *general facies* of the plants and animals that lived during the Silurian epoch differs considerably

from the facies of the Devonian flora and fauna, but it is not true that the strata we call Silurian imbed a system of life altogether distinct and different from that imbedded in the strata we term Devonian. The groups and systems and periods of the geologist must be received as mere provisional expedients towards the elucidation of his science; and we sin against nature the moment we attempt to set them up as the exponents of what some are in the habit of styling "independent creations." Geology cannot point its finger to a single break in the great evolution of vitality, any more than it can point to a moment's cessation in the physical operations of nature, from the deposition of the first-formed strata to the layer of mud left along shore by the last receding tide. The whole of our groups and systems are merely successive stages in one great system or COSMOS—the minor stages imperceptibly graduating into each other, and the amount of progress becoming apparent only after the lapse of ages. These progres*sional stages constitute, in fact, our "systems" and "periods;"* and if in one region there should appear to be a sudden break between them, let the student ever remember that the deficiency is supplied by some other district—in other words, let him remember that the oscillations of sea and land, of elevation and depression, and other physical changes of condition, are sufficient to account for local breaks in Life, but that there is no foundation whatever for the belief in "general extinctions," and consequently "new general creations." So far as the few thousand years of man's personal observation extends, the current epoch is as mutable as any of the epochs that preceded, and yet so gradual have its extinctions and creations taken place, that science can scarcely corroborate the one, and has as yet failed to detect the other. The systems of the geologist are therefore mere concatenations of events indicative of certain periods of time; and as nature never repeats herself, each period, when taken at sufficiently distant intervals, is characterised by *some* peculiar forms of vitality, the while that its *general* life merges imperceptibly into that of the epoch that follows, just as it was inseparably interwoven with that which preceded.

Theoretical Deductions.

365. By a study of the systems and periods of the geologist, we arrive, if not at a complete history of the globe, at all events

at some of the main features and conclusions of such a record. And,

1*st* of all, we arrive at the fact, that from the deposition of the first stratified rock to the present moment, the same kind of agencies have operated on and modified the rock-materials of the globe—that then, as now, sands and sandstones, gravels and conglomerates, silts and shales, vegetable drift and animal debris, were accumulated and consolidated precisely in the same way, and by similar agencies. How far these agents acted with greater intensity during former epochs, or were subject to alternating periods of violence and repose, has been already considered.

2*d*, That then, as now, the world had its oceans and continents, its seas and islands, its lakes and rivers and estuaries, its valleys and plains and hills—the one being wasted and worn down, the other forming basins of reception for the transported material. With regard to the areas and successive distributions of these, the stratified formations afford us some idea, though repeated upheavals and depressions render the mapping out of these ancient seas and lands a difficult, if not an impossible, task. All that we can arrive at is a mere approximation; but vague as this approximation may be, it is sufficient to confute the hypothesis entertained by some geologists of an all but "universal ocean" at any epoch of the earth's history, and to establish the fact that continents and islands, seas, gulfs, and estuaries, of various dimensions, and variously distributed, existed throughout all the stratified systems, as they do now. It is true, we can note the increments of existing continents, and point to a time when they rose as mere shallow shoals and clusters of islands; but we cannot trace the dimensions of the continents now submerged beneath the ocean, nor trace the course of the rivers that bore from their hills and plains the sediments that went to form the increments in question. The idea of "seas of unfathomable depth" as applicable to any period of the earth's history more than another, is also untenable—littoral conglomerates and sandstones, shallow shell-beds, and deeper coral-growths being common to every formation, from the Cambrian up to the latest Post-tertiary.

3*d*, That then, as now, while certain regions enjoyed quiescence and repose, others were upheaved and convulsed by igneous commotion; but we have as yet no certain proof, though many facts seem to favour the belief, that igneous manifestations were either more general or more frequent during the earlier epochs of the world. Could we establish the fact of the earth having cooled

down from a state of molten incandescence to its present temperature, the greater intensity of igneous action during earlier eras would form part and parcel of the problem. As it is, we can only admit the probability of such conditions, and look to the most gigantic hill-ranges as the growth of ages—the tertiary manifestations of the Alps outrivalling in grandeur and altitude the primeval ridges of the Dofrafelds or Grampians.

4th, That then, as now, the earth was enveloped by an atmosphere, had its clouds and rains, its sunshine and showers, had its seasons of growth and periods of repose; and though many facts seem to favour the idea of a uniform and equable climate over more extensive regions during the earlier epochs, and it may be even some slight change in the composition of the atmosphere, geology has yet no direct proof to offer, and must content itself by *merely admitting the probability of such conditions and contingencies*. The areas in which the plants of the coal period flourished must have enjoyed a mean temperature, it has been calculated, of at least 22° Reaumur, and the mean temperature of the globe is now from 12° to 16° less; but it is far from being *proved that the coal plants flourished universally, or were even* of tropical or sub-tropical character. On the contrary, the more we know and study the relations of our coal-fields and their fossils, the more we are constrained to abandon the idea of tropical warmth, and to adopt the belief in only a moist and *uniform climate, favoured by geographical conditions of* river-swamps, estuarine and marine jungles, and far-spreading mud-flats, over which a peculiar and rapidly-growing vegetation flourished, decayed, and flourished for ages of slow terrestrial subsidence. Again, instead of the earth having enjoyed a higher *temperature in earlier epochs, or having been superficially influenced* by its internal heat, we have every reason to suspect the recurrence of colder and warmer cycles in obedience to some great cosmical law—these colder cycles being evidenced by the azoic grits of Cambria, the scanty flora and fauna of the Old Red conglomerates, the Permian breccias, and the boulder-clays of the Pleistocene epoch—the intermediate warmer cycles over the same areas marking the Silurian, coal, oolite, and earlier tertiaries. We have also further evidence of *seasons* as well as of *cycles* of ungenial climate, the coniferæ of the secondary strata exhibiting larger and smaller concentric rings,—the effects of favourable and unfavourable influences.

5th, That during all epochs, as at present, the earth and waters were tenanted by various families of plants and animals, dis-

tributed by the laws which now regulate their existing provinces, and fitted to perform analogous functions in the economy of nature. It is true that as we descend into the rocky crust, we arrive at a stage (the metamorphic strata) where plants and animals do not seem to have existed; but on this point the evidence is merely negative, and geology cannot say with certainty that life was not coeval with the globe itself, though the presumption is that plants and animals were not called into existence till about the dawn of the Cambrian era. At whatever stage the first creation of plants and animals took place, one type and plan of being has ever run throughout the whole; analogous functions have had to be performed; and the various biological provinces have been peopled, partly by identical, and partly by representative species.

6th, The origin of life necessarily implies the fitness of the globe for its sustenance, and on this point the geologist is compelled to entertain the hypothesis, whether the globe has not gradually cooled down from a state of molten incandescence to its present temperature. On this head it must be admitted that science is deficient in direct evidence, though the facts adduced in Chapter II. go far to sustain the belief of such a gradual refrigeration, and the consequent introduction of life at the stage compatible with its existence. If such has been the case, the internal heat must have been felt more sensibly at the surface than now, and hence a more equable and uniform climate all over the globe; but of such a higher and more equable temperature, we have certainly no evidence since the deposition of the earliest fossiliferous strata. And let it also be observed, that it by no means follows uniformity of climate should be accompanied by identity of species; on the contrary, while it is admitted that a general facies pervades the flora and fauna of tropical America, tropical Africa, and tropical India, the species are there quite as distinct and peculiar as they are in biological provinces the most distant and climatologically different.

7th, As each system is characterised by its own peculiar plants and animals, the question naturally arises whether these are independent creations, or whether there is in nature some law of development by which, during the lapse of ages, and under change of physical condition, the lower may not be developed into higher species, and the simpler into the more complex. On this topic much has been said and written, but, after all, Geology is not in a position to solve the problem of vital gradation and progress. It cannot tell, for example, why trilobites should have

flourished so profusely during the silurian epoch, and have died out before the deposition of the oolite; why chambered cephalopods should have culminated, as it were, during the liassic era, reptilian life during the oolite and chalk, or why mammalian development should have been reserved to the tertiary and current epochs. All that it can assert, and assert with some degree of confidence, is, that while the higher races seem to have followed the lower in point of time, there is no evidence that the higher types of an order always succeeded the lower; on the contrary, many of the earlier mollusca, crustaceans, and fishes, were of more complex organisation than those of the same families now peopling existing waters.

8th, The study of life, palæontologically regarded, necessarily involves the creation and first appearance of Man on the globe; and on this subject much discussion has taken place, unprofitable alike to science and to the cause of Christian theology. So far as geological evidence goes, we have no trace of man or of his works till we arrive at the Superficial Accumulations—the coral conglomerates, the bone-breccias, the cave-deposits, the river-silts, and the peat-mosses—of the current epoch. It is true, that so far as the earlier formations are concerned, the evidence is purely negative; but, taking into account all that palæontology has revealed touching the other families of animated nature, the fair presumption is that Man was not called into being till the commencement of the current geological era, and about the time when, in the northern hemisphere, the sea and land received their present configuration, and were peopled by those genera and species which (with a few local removals and still fewer extinctions) yet adorn their forests and inhabit their land and waters.

9th, Whatever may have been the creational development of plants and animals, the groups and systems of Geology afford irrefragable evidence of the lapse of vast epochs and cycles of time. The idea of immeasurable duration is at once suggested by an examination of the stratified rocks,—their innumerable alternations, their thickness, their repeated laminations, the alternation of marine with fresh-water beds, their upheaval into dry land and subsequent submergence again and again, the various races that have lived and grown and been entombed in them, system after system,—all this, and much more that will readily suggest itself to the student, must convince him beyond doubt of the almost inconceivable duration of geological time. To attempt to compute this time by years and centuries is altogether futile; we can only

faintly indicate its vastness by the use of indefinite terms, as "eras" and "epochs," "cycles" and "systems." Many ingenious calculations have, no doubt, been made to approximate the dates of certain geological events, but these, it must be confessed, are more amusing than instructive. For example, so many inches of silt are yearly laid down in the delta of the Mississippi—how many centuries will it have taken to accumulate a thickness of 30, 60, or 100 feet? Again, the ledges of Niagara are wasting at the rate of so many feet per century—how many years must the river have taken to cut its way back from Queenstown to the present Falls? Again, lavas and melted basalts cool, according to the size of the mass, at the rate of so many degrees in a given time—how many millions of years must have elapsed, supposing an original igneous condition of the earth, before its crust had attained a state of solidity? or further, before its surface had cooled down to the present mean temperature? For these and similar computations, the student will at once perceive we want the necessary uniformity of factor; and until we can bring elements of calculation as exact as those of astronomy to bear on geological chronology, it will be better to regard our "eras" and "epochs" and "systems" as so many terms, indefinite in their duration, but sufficient for the magnitude of the operations embraced within their limits.

10*th*, On the whole, these groups and systems of the geologist—imperfectly interpreted as they yet undoubtedly are—present a long series of mineral mutations, and of vital gradation and progress. Not progress from imperfection to perfection, but from humbler to more highly organised orders, as if the great design of nature had been to ascend from the simpler conception of *materialism* to the higher aims of mechanical combination, from *mechanism* to the subtler elimination of mind, and from *mentalism* to the still nobler attribute of *moralism*, as developed alone in the intellect and soul of man. From the lowly sea-weeds of the silurian strata and marsh-plants of the old red sandstone, we rise (speaking in general terms) to the prolific *club-mosses, reeds, ferns, and gigantic endogens* of the coal-measures; from these to the palms, cycads, and pines of the oolite; and from these again to the exogens or true timber-trees of the tertiary and current eras. So also in the animal kingdom: the graptolites and trilobites of the silurian seas are succeeded by the higher crustacea and bone-clad fishes of the old red sandstone; these by the sauroid fishes of the coal-measures; the sauroid fishes by the gigantic saurians and

reptiles of the oolite; the reptiles of the oolite by the huge mammalia of the tertiary epoch; and these in time give place to existing species, with Man as the crowning form of created existence. This idea of gradation implies not only an onward change among the rock-materials of the earth, but also, as plants and animals are influenced in their forms and distributions by external causes, new phases and arrangements of vitality—the creation of new species, and the dropping out of others from the great scheme of animated nature. And such is the fact even with respect to the current era. The mastodon, mammoth, and other huge pachyderms that lived from the tertiary into the modern epoch, have long since become extinct, leaving their bones in the silts and sands of our valleys. The elk, urus, bear, wild-boar, wolf, and beaver, are now extinct in Britain; and what takes place in insular districts must also occur, though more slowly, in continental regions. The dodo of the Mauritius, and the dinornis of New Zealand, are now matters of history; and the same causes that led to the extinction of these, seem hurrying onward to the obliteration of the beaver, ostrich, apteryx, elephant, kangaroo, and other animals whose circumscribed provinces are gradually being broken in upon by new conditions.

11*th*, In reasoning on the causes which have led to the extinction of races, we must not lose sight of the speculation that species, like individuals, may have had a limit of duration assigned to them from the beginning, and that this limit may be attained even while all extraneous causes remain quiescent and stationary. "Attempts have been made," says Professor Owen, "to account for the extinction of the race of northern elephants (the mammoth of Siberia) by alterations in the climate of their hemisphere, or by violent geological catastrophes, and the like extraneous physical causes. When we seek to apply the same hypothesis to explain the apparently contemporaneous extinction of the gigantic leaf-eating megatherium of South America, the geological phenomena of that continent appear to negative the occurrence of such destructive changes. Our comparatively brief experience of the progress and duration of species within the historical period, is surely insufficient to justify, in every case of extinction, the verdict of violent deaths. With regard to many of the larger mammalia, especially those that have passed away from the American and Australian continents, the absence of sufficient signs of extensive extirpating change or convulsion makes it almost as reasonable to speculate with Brocchi on the possibility that species, like individuals, may have had the cause of their death inherent in their original constitution, independently of

changes in the external world, and that the term of their existence, or the period of exhaustion of the prolific force, may have been ordained from the commencement of each species."

12th, The removal and extinction of species taken in connection with the physical changes that are continually taking place on the surface of the globe, necessarily lead to speculations as to the conditions and phases of the Future. Respecting these, however, it were in vain to offer even the widest conjecture. Subjected as our planet is to the numerous modifying causes already described, we know that vast changes are now in progress, and that the present aspect of nature will not be the same as those she must assume in the eras that are to follow. But what may be the nature and amount of these changes, what the new conditions brought about by them, or what the races of plants and animals adapted to these conditions, science has yet no available means of determining. This only the philosophical mind rests assured of, that as in the Past the changes were always gradual and local, and the newer phases ever bore a certain appreciable relation to those that went before, so in the Future we may rely on a similar gradation, and believe that the differences between the phases yet to be will never exceed those Geology has discovered between any two successive epochs, and that, as throughout the whole of the past, so throughout the whole of the future, the great COSMICAL DESIGN which Science now labours to reveal, will be steadily upheld by the Omniscient omnipotence of Him "with whom is no variableness, neither shadow of turning."

366. From the generalisations attempted in the preceding paragraph, the student cannot fail to perceive the imperfect but progressive state of his science—to discover how much has been done, but how much more remains to be accomplished. To this desirable object he will best contribute by diligently collecting new facts, and rigidly observing the rules of correct induction. There is little to be gained by indulging in surmise and hypothesis, however curious and ingenious, unless they are based on fact and observation. So founded, they may lead in time to a correct theory of the earth, and such a theory is the legitimate end of all geological inquiry. The curious in these matters may readily indulge their curiosity by such *Theories of Creation* as those of Woodward, Whiston, Burnet, Buffon, Cuvier, and many others of lesser note. On the subject of vital development, the student may refer to the writings of Lamarck; *Vestiges of the Natural History of Creation*, an anonymous attempt to popularise the Lamarckian hypothesis; Hugh Miller's *Footprints of the Creator*; Darwin's *Origin of Species*; and to many able papers on the

subject in the *Edinburgh*, *British Quarterly*, and *North British Reviews*, in *Silliman's Journal*, and other periodicals, called forth by the appearance of the *Vestiges* in 1844, and the *Origin of Species* in 1860, and attributed to the pens of Professor Sedgwick, Sir David Brewster, Professor Hitchcock, Dr Asa Gray, Agassiz, and others. Of higher import than these, and founded on more thorough scientific acquaintance with the subject, are—a paper *On Life and its Successive Developments*, by Professor Owen, in the 89th volume of the *Quarterly Review*; and deeper and fuller still, the magnificent *Essay on Classification*, by Professor Agassiz. On the general state of geological theory, the student will find important hints in the *Manuals* of Phillips and Lyell, in De La Beche's *Theoretical Geology*, in the *Theoretical Researches* of Professor Bischoff of Bonn, and in an admirable paper entitled "Geology," by Mr Hopkins, in the *Cambridge Essays* for 1857. On the whole—and we again repeat it—he will be better employed in dealing with fact and description, and avoiding hypotheses and speculation, for which the state of the science is yet but very slenderly prepared.

XX.

ECONOMIC ASPECTS OF THE SCIENCE—METHODS OF PRACTICAL PROCEDURE.

367. LIKE other branches of natural history, Geology has its *economic* as well as its *scientific* aspects. In a theoretical or purely scientific point of view, we have seen the high intellectual aim and universal interest of its problems; in a practical sense, its importance is not less immediate to civilised nations, whose progress, wealth, and comfort depend so largely on a knowledge of those minerals and metals, without which perfection in the arts and manufactures would be altogether unattainable. In the present chapter we shall, therefore, indicate to the student the main practical bearings of the science, leaving him to gather from works on Mining, Engineering, Metallurgy, Architecture, and Agriculture all that relates to the application of its industrial and commercial details. Throughout the work we have adverted to the economic products derived from the respective systems, more with a view to familiarise the student with their lithology, than to inculcate lessons on practical geology; yet, slight as our indications have been, enough has been given to show how vast and valuable the substances derived from the crust of the earth, and how varied their applications in the industry of civilised nations. While it is desirable, therefore, that every educated mind should possess some acquaintance with the leading facts of the science, a knowledge of its principles becomes indispensable to the miner, the engineer, the builder, the farmer, and land-valuator, the landscape-gardener, the artist, and the geographer, on whom we rely for correct and available descriptions of foreign and unknown lands. It is necessary, however, to draw a clear line of distinction between the duties of the practical or consulting geologist, and those, for example, of the miner, the engineer, or builder. The one collects facts, and establishes therefrom certain generalisations; the others merely avail themselves of these

generalisations, and apply them to their own special requirements. As the sailor navigates his vessel by the data of the mathematician and astronomer, without holding them responsible for the mischances of shipwreck, so ought the miner and engineer to found their plans on the conclusions of the geologist, without involving his science in the blunders or failures of their execution.

Mining—Engineering—Building.

368. Deriving all our mineral and metallic treasures—our coal and iron, our gems and precious metals—from the crust of the earth, it is of vast utility to be able to discriminate between mineral substances, to determine in what formations they occur, and to say where they are or are not to be found. The *miner* cannot proceed a step in safety without the guidance of mineralogy and geology; and though mining existed long before the truths of science assumed a technical aspect, yet do its operations proceed with certainty and precision only in proportion to the advancement of scientific generalisation. The operations of the miner come under three grand categories—digging in superficial clays and gravels, like the stanniferous debris of Cornwall and the auriferous deposits of California and Australia; mining in stratified formations, as for coal and ironstone; or following after those metalliferous veins that traverse the crust in vertical and highly-inclined directions. Each of these three positions requires from the mining-engineer different appliances and different operations, and this is his special vocation; but their positions, their modes of occurrence, their continuity and persistency, and the circumstances connected with their origin which may influence one or all of these, are matters that belong to correct geological deduction. Having determined, for example, the age of certain mountain ranges, the geologist can predict whether the river-drift, which in course of time has been borne from their cliffs and ridges, is auriferous or barren; having examined a few fossil stems and leaves of a coal district, he can tell with unerring certainty whether it belongs to the carboniferous, the oolitic, or cretaceous epoch, and so predicate as to the extent, persistency, and value of its coal-beds; or having ascertained the directions of the leading lodes and cross-veins in any metalliferous district, and their relative antiquities, he can arrive at a pretty accurate estimate of their richness and value. Without this geological knowledge, square miles of gravel have been turned over without discovering a single nugget; and thousands have been spent in the fruitless

search for coal where coal was never deposited. To the non-geological miner a red sandstone is a red sandstone and nothing more; but whether above or beneath the coal he is in search of, he cannot tell. To the geologist, on the other hand, the head of a *cephalaspis*, or the scale of a *holoptychius*, decides the question, and the "red sandstone" becomes pregnant with hope, or holds out the warning to proceed no farther in fruitless explorations. Besides determining the position in which coal, ironstone, and other useful strata occur, geology can direct the miner through all those obstructions occasioned by faults, dykes, slips, and the like; for even these, irregular as they seem, bear certain evidence of their direction—upthrow or downthrow—which the experienced eye can readily detect. As with the minerals of commerce that occur *in strata*, so to a certain extent with the ores of lead, copper, tin, silver, and gold, which are found *in veins* and *lodes*. These veins follow certain courses in relation to the great axis of elevation with which they are associated, are interrupted by cross dykes and veins, are thrown up or down by dislocations—all of which an experienced geologist can determine and lay down on his map, so as to save much fruitless waste of labour and capital, or, what is often as necessary, to prevent unprincipled gambling and ruinous speculation.

369. The importance of geological knowledge to the *civil-engineer*—to the constructor of roads, railways, and canals, the excavator of tunnels, the sinker of wells, and the drainer of cities—is so obvious, that the fact requires little illustration. Possessed of a carefully-constructed lithological map, on which are delineated the various kinds of strata, their dip, strike, and other particulars, the engineer who can read these facts aright has a surer guide than the scanty and scattered data of his own boring-rod. He sees at once the nature of the rocks through which his work has to pass—whether road, railway, or canal; can estimate with certainty the expense of construction, and avail himself of minerals which he knows must lie in the vicinity; while one ignorant of geological truths would blindly pass by such advantages. In fixing a line of road or railway, the geological engineer will avail himself not only of facilities for present construction, but calculate, from his lithological knowledge of the district, for the future benefit of those concerned in the undertaking. In the case of canals, moreover, where retention of water is indispensable, the geologist can effectually aid in the selection of a route, by attending to the nature and dip of the strata, and to the fractures and dislocations to which they have been subjected. He is enabled, from his knowledge of the rocks and their posi-

tions, not only to prevent waste of water, but to select a rout where fresh supplies can be readily obtained from below. A with roads and canals, so with tunnels, docks, Artesian wells supply of water for towns, and other undertakings commonl intrusted to the civil-engineer. It is true that such works ma often be satisfactorily enough completed without the aid of geo logy, but undoubtedly a knowledge of its deductions will mate rially assist, by conferring a certainty and security on what woul otherwise be a mere patchwork of trial and error. We have seen for instance, a tunnel carried through the wet and highly-incline strata of a hill where every foot had to be arched with brick o stone, while the deviation of a few hundred yards would have car ried the same through rock-masses, where not an inch of buildin would have been necessary. In ignorance of the limits of a coal field, we have seen a railway carried along the outskirts, to whic every coal proprietor has to lay down miles of tramway, mor than the half of which would have been saved had the enginee had the necessary knowledge to have adopted a central course The strata of the London, Hampshire, and Paris basins are no so well known to geology, that Artesian wells can be sunk wit certainty to this or that stratum ; and so with every other dis trict whose strata have been mapped and generalised by the geo logist. Again, in deciding upon the collecting-field for the water supply of large towns, a knowledge of the rocks of the area i indispensable, so that deleterious mineral ingredients may b avoided, new lines of springs tapped, and waste by subterranea fissures and faults prevented. As with the leading-in of pur water, so with the carrying out of that which has become impure and deleterious ; the more the engineer knows of the rock-forma tions of the district, the less risk he runs of failure, or of incurring an unremunerative and ruinous expenditure.

370. The *builder* and *architect* may also derive important assistance from the geologist, both as regards the durability of certain rocks, their position, and the facility with which they may be obtained. By observing the effects of the weather on strata exposed in cliffs and other natural sections, the geologist can readily pronounce as to their durability ; while, aided by the analyses of the chemist, and experiments on their power of resisting pressure, the facility with which they absorb moisture, their quality of hardening on exposure to the air, and so forth, he can also determine their fitness for any particular structure. The amount of waste shown by the various stones in old ecclesiastical and baronial buildings is another safe and valid test ; and it is the travelled geologist—the man who knows the rocks of a dis-

trict, and not the mere builder—who can point to the locality, nay, to the very stratum, whence the stones of the buildings were quarried. In Britain, we have a great variety of building-stone, as the Bath and Portland oolites, the marbles of Devonshire, the magnesian limestones of Derby, York, and Durham, the new red sandstones of Liverpool and Carlisle, the carboniferous sandstones of Yorkshire, Newcastle, Glasgow, and Edinburgh, the old red sandstones of Perth, Forfar, and Caithness, the granites of Aberdeen, and the basalts and porphyries of numerous localities. Each of those has its peculiar quality of weight, hardness, strength, colour, facility of dressing, cheapness, and so forth; and while these are matters for the builder and engineer to test and decide, still there are many points on which the advice of the geologist may be taken with obvious advantage.

Agriculture—Landscape-Gardening—Painting.

371. The assistance which geology is calculated to confer on the science of *Agriculture*, though somewhat overrated at one time, is certainly among the most obvious of its practical features. All fertile soils consist of two classes of ingredients—organic and inorganic; the former derived from the decomposition of vegetable and animal matter, the latter from the disintegration of the subsoil or of the subjacent rock-masses. Without a certain proportion of organic matter no soil can be fertile, hence the continuous application of animal and vegetable manures; but it is equally true that without a due admixture of inorganic or mineral compounds all attempts at its permanent improvement will be fruitless. All the mineral elements essential to fertility may not exist in the soil of a particular locality; but the moment that chemical analysis has indicated the deficiency, the farmer can readily obtain the required ingredient from some other district or it may be from the subsoil of his own fields, and so effect the permanent improvement in question. To do this, however, he requires to know not only the chemical composition of rocks and soils, but the precise spots they occupy; in other words, he must be familiar with the language and delineations of a geological map of his own district, and know the lithological peculiarities of the respective formations. We have already stated (par. 316) that for agricultural purposes two sets of maps are necessary—one exhibiting the nature and area of the superficial accumulations, and another devoted, as usual, to the rock-formations that lie below. Aided by such helps, and sufficiently acquainted with the science

to be able to take advantage of their assistance, the geological farmer has a power at his command which he may turn to the best account, either in the permanent improvement of the soil he occupies, or in the choice of a farm for carrying on the operations of some special department of husbandry. Besides the permanent admixture of inorganic substances, there are other conditions necessary to increased fertility; such as facilities for drainage, capability of retaining moisture, the innocuous nature of the subsoil, and the power of absorbing and retaining the solar heat. Soil overlaying trap and limestone requires less artificial drainage than that covering the coal-measures, the new red marls, or wealden, because the former rocks are traversed by numerous joints and fissures which act as so many natural drain-pipes, while the latter are chiefly tenacious and impervious clays. Again, land of itself dry and friable may be rendered wet by springs which arise along some line of dislocation. The farmer acquainted with the deductions of geology would cheaply lead off these springs at their source, while he who was ignorant would laboriously furrow-drain his whole field, and find, after all, that his was the less effectual method of the two. Such are mere indications of the assistance which geology is calculated to confer on agriculture—an assistance very apt to be overrated, however, unless the farmer at the same time avail himself of the assistance of the chemist, meteorologist, and vegetable physiologist. As with the farmer, so with the *land-valuator;* and though a shrewd practical man who has travelled a good deal and kept his eyes open to points of amenity, facilities for market, and so forth, may often approximate very closely to the real value of an estate, depend upon it another possessed of the same shrewdness and experience, and skilled in the geological bearings of the district to boot, will be much the safer guide. In fact, without a knowledge of the mineral structure of an estate, it is altogether impossible to ascertain its value; and so it has happened, even within the last twenty years, that estates have been sold at so many years' purchase of the land-rent merely, and in total ignorance of a mineral wealth that might have been fairly suspected from the most cursory glance of a geological map of the district. It may be true that the functions of the land-valuator are altogether distinct from those of the mineral-surveyor, and that the report of the one should be accompanied by the report of the other; but even in the valuing of land for mere agricultural purposes, the man who is ignorant of the mineral facilities of a district—its limes, clays, marls, shell-sands, phosphates, and so forth—can give but a very uncertain and unsatisfactory opinion.

372. As the scenery of every district is less or more influenced by its geological structure and formation, a knowledge of these formations cannot fail to be of use to the landscape-gardener and artist. "If, in order to draw correctly the human figure," says Mr Ansted, "it is desirable to be acquainted with the anatomy of the human frame, and study the hidden cause of those numerous prominences and projections which give character and expression when clothed with flesh, it is no less necessary that the landscape-painter should study the nature and conditions of rocks, their usual forms, possible modifications, and the way in which they are likely to be covered up, masked, or modified by atmospheric and aqueous action. It has been well said, by the author of *Modern Painters*, 'The laws of the organisation of the earth are distinct and fixed as those of the animal frame—simpler and broader, but equally authoritative and inviolable. Their results may be arrived at without knowledge of the interior mechanism; but for that very reason ignorance of them is the more disgraceful, and violation of them more unpardonable. They are in landscape the foundation of all other truths—the most necessary, therefore, even if they were not in themselves attractive. But they are as beautiful as they are essential; and every abandonment of them by the artist must end in deformity, as it begins in falsehood.'" Throughout the work we have drawn attention to the physical features of the respective formations, and here we need only observe that the artist acquainted with the causes that have conferred, for example, a bold and rugged outline on primitive mountain-ranges, and a smooth and swelling one on hills of secondary districts—who can appreciate the distinction between the splintery crags of the slate-formation and the wall-like precipices of the mountain limestone, the rugged and jagged cliffs of a metamorphic shore, and the softer though equally lofty ones of the chalk—who can feel the effect of a long line of stratified coast composed of the coal-measures or lias as compared with the vertical arrangements of the igneous rocks—and who knows, moreover, the effects of rock-formations on vegetable growth, and the natural disposition of that vegetation around and over the cliffs and crags he portrays—is much more likely to succeed in his art than one who is ignorant of or indifferent to such natural causes and peculiarities. And what is true of landscape-painting applies with still greater force to landscape-gardening and the fencing and planting of estates. We have seen belts and clumps of woodland arranged where nature would never have planted them, the finest cliffs obscured by plantings that nature would never have permitted, and rockeries and rock-work set down where the

slightest acquaintance with geological phenomena would have told the artist that rocks and cliffs could never have existed.

As a Branch of General Education.

373. Nor is it alone the miner, the engineer, builder, farmer, landscape-gardener, and painter, that can turn to profitable account the deductions of geology. The capitalist who speculates in land, the emigrant, the traveller and voyager, the statistician and statesman, may all derive assistance from the same source, and bring a knowledge of its facts to bear on the progress of their nations. So also the holiday tourist, the military officer stationed in distant countries, and others in similar situations, if possessed of the requisite knowledge, may do good service not only to the cause of science, but to the furtherance of our industrial prosperity. Indeed, we do not affirm too much when we assert that had one tithe of those who, during the last fifty years, have travelled or settled in America, Australia, New Zealand, India, and other countries, been possessed even of a smattering of geology, these countries, as to their substantial wealth and social progress, would have been in a very different position at the present day. Their gold-fields and coal-fields, their mines of iron, copper, and other metals, take rank among the most important discoveries of the present age; and as the spirit of civilisation is now evolved and directed, no progress can be made without those mechanical appliances to which the possession of coal and iron is indispensable, no facility of commercial intercourse without a sufficiency of gold, which has hitherto formed the most available medium of interchange.

374. The assistance which geology has also conferred, and the new light its deductions have thrown on the other branches of natural science, are not among the least of its claims to general attention. The comparatively recent science of Physical Geography, in all that relates to the surface-configuration of the globe—its climate and temperature, the distribution of plants and animals, and even touching the development of Man himself, as influenced by geographical position—can only lay claim to the character of a science when treated in connection with the fundamental doctrines of geology. So also in a great degree of Botany and Zoology; the reconstructing, as it were, of so many extinct genera and species, has given a new significance to the science of Life; and henceforth no view of the vegetable or animal kingdom can lay claim to a truly scientific character that does not embody

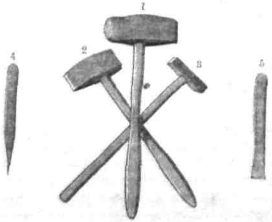
the discoveries of the Palæontologist. In fact, so inseparably woven into ONE GREAT SYSTEM OF LIFE are fossil forms with those now existing, that we cannot treat of the one without considering the other; and can never hope to arrive at a knowledge of Creative Law by any method which, however minute as regards the one, is not equally careful as concerns the other. Combining, therefore, its theoretical interest with its high practical value—the complexity and nicety of its problems, as an intellectual exercise, with the substantial wealth of its discoveries—the new light it throws on the duration of our planet and the wonderful variety of its past life, with the certainty it confers on our industrial researches and operations—Geology becomes one of the most important of modern sciences, deserving the study of every cultivated mind, and the encouragement of every enlightened government. Year after year this truth is pressing itself more forcibly on public attention, and now the most important states of Europe and America have their "schools of mines" and "geological surveys;" while our own colonies—Canada, India, Australia, New Zealand, and the West Indies—are beginning to reap the advantages of official and systematic exploration.

Procedure in the Field.

375. To acquire a knowledge of the science thus sketched, sufficient for the purposes of a well-informed mind, is not a very difficult or tedious task. The objects of research, we have already said (par. 12), are scattered everywhere around us. Not a quarry by the wayside, not a railway-cutting through which we are carried, not a mountain-glen up which we wander, nor a sea-cliff under which we saunter on a summer's evening, but furnishes, when duly observed, important lessons in Geology. A hammer to detach specimens, and a bag or basket to carry them in—a pocket magnifying-lens to detect minuter structures—a compass and clinometer to determine the strike and dip of strata—a sketch-book to note unusual phenomena—an observing eye and a pair of willing limbs—are nearly all the young student requires for the field; and by inspection and comparison in some museum (and luckily these are everywhere on the increase), and by the diligent use of his text-book, he will, after a few rambles, be able to proceed in the study as a practical observer. Let him note every new and strange appearance, handle and preserve every rock and fossil with which he is not familiar, throwing nothing aside till he has become familiar with its nature; and thus,

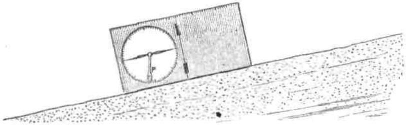
besides obtaining new knowledge and facilitating his progress, he will shortly acquire the invaluable power of prompt and accurate discrimination. By following such a course, it is astonishing how soon the eye is trained to detect the faintest trace of an organism, the nature of a mineral crystal, or even the composition of a rock, and to be in a great measure independent of mineralogical tests or chemical analyses.

376. The equipments for the field, we have said, are neither numerous nor expensive; and here we may remind the young student that it is of much more importance to know the thing sought after than to be curious about the shape of a hammer, the cut of a bag, or the style of his general accoutrement. One of the Nestors of English geology makes boast of never having spent a guinea on field equipments; and yet the science is perhaps as much indebted to him as to any other name on the roll of living geologists. As to *hammers*, these can now be readily obtained from almost any ironmonger. One with a round end, like No. 1, for hard and massive rocks; another with a flat end and cleaving face, like No. 2, for softer strata; and a third, of the shape of No. 3, for dressing and chipping cabinet specimens, are all that is necessary; and if to these are added *chisels* of the shapes here indicated (4 and 5), the student requires nothing



more. In general, he will find it convenient to carry his hammer and chisels sheathed in a *waist-belt*, both because they are more readily got at, and more easily carried when his bag gets filled with specimens. As to a *bag*, one of stout jane or canvass, with two divisions and a pocket, will be amply sufficient. If on a long ramble, one of the divisions can hold his night-traps, the other his specimens, while the pocket may be appropriated to his flask and biscuits. An *eye-glass*, with two or three lenses and dia-

phragm, can be procured from any respectable optician for a few shillings; and the instrument-makers in most of our large towns now keep in stock a neat *pocket-compass*, fitted with a brass pendule (p), to be used when required as a *clinometer*. The student



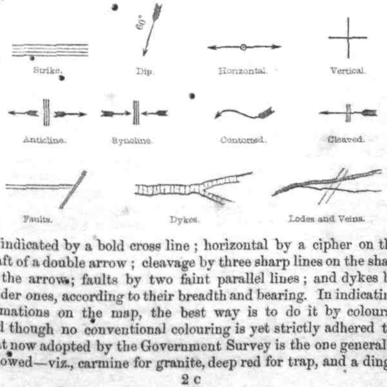
may even construct his own clinometer—a piece of cardboard, marked with the degrees, and fitted with a swinging slip of metal for a pendule, being quite as useful as the most expensive he could purchase. An *acid-bottle*, and a few other simple tests, are also extremely useful in the field; but anything like analysis must be reserved for the laboratory. For ascertaining heights up to 2000 feet or thereby, the *aneroid* will be found the most convenient instrument for the geologist, who seldom requires, in the British Islands, to carry with him into the field either the *barometer* or *thermometer*. Of course it is different when travelling among unknown heights, or in districts abounding in hot springs and other thermal phenomena. A *note* or *sketch book* is an indispensable requisite; and every day spent in the field without it may be looked upon as a day all but lost to the geologist. It is quite impossible for the memory to carry away a multiplicity of details as to strike, dip, inclination, contortion, joints, faults, veins, &c., or even to retain the aspect of rock-masses with sufficient accuracy for future reference and comparison. Once noted, however, and they are available ever after. *Personally*, the lighter a geologist can travel the better; a thin waterproof cape, in the event of rain (an umbrella is an incumbrance and obstruction), a short shooting-coat with a superabundance of pockets, a pair of stout-soled easy-going shoes, and a spare pair of socks, is all that he need provide for the roughest and longest excursion.

377. Thus equipped, he should carry with him *the best map of the district* he can procure, and if coloured geologically, so much the better. A large portion of England and Ireland has now been surveyed and mapped by the Government geologists, and the sheets of this survey are decidedly the best and most available. For districts of the country not yet officially surveyed,

such maps as Knipe's or Phillips's "British Isles," Ramsay's or Murchison's "England," Griffiths's "Ireland," Nicoll's, Knipe's, or Murchison's "Scotland," or the "Palæontological Map of the British Islands" in Keith Johnston's *Physical Atlas*, will be found to be of essential service. There are also variously published sets of *county maps*, several of which have been coloured geologically, to accompany local memoirs; and these, though often imperfect, will be found to be of use in pointing out the boundaries of formations and other peculiarities. In making his investigations, the student should examine every exposed face or section of rock; and for this purpose sea-cliffs, sides of ravines, mountain precipices, river-channels, road and railway cuttings, quarries, wells, coal-pits, and, in short, every surface-opening, should be sought after. As he travels along, he should also learn to note the stones used for road-metal, for field-fences, and other country purposes, and those will often guide him to local quarries which he might otherwise have missed. The ordinary buildings of a district are also in general good indices to its geological formations, though occasional architectural stones are brought from a great distance, and thus present the geologist with some curious anomalies. The young explorer should also make the acquaintance of every stone-breaker, quarryman, miner, and mason he meets with; and though the terms "Metamorphic," "Silurian," "Devonian," and the like, may be as High Dutch to their ears, yet, if conversed with in their own language, many of them will be found to afford important information both as to the nature of the rocks, the stratification, the faults, and other particulars of a district. In fine, the student should let no stone lie unturned to get at the object of his investigation; should visit the local museum, if there is one; find out the names of local collectors, and get access to their cabinets; call at the shop of the working lapidary and dealer in natural curiosities; and it must be a very obscure village, or a very uninteresting locality, geologically speaking, that does not possess some one curious in fossils, minerals, pebbles, shells, insects, or the like, and who knows something, less or more, of the natural history of his district.

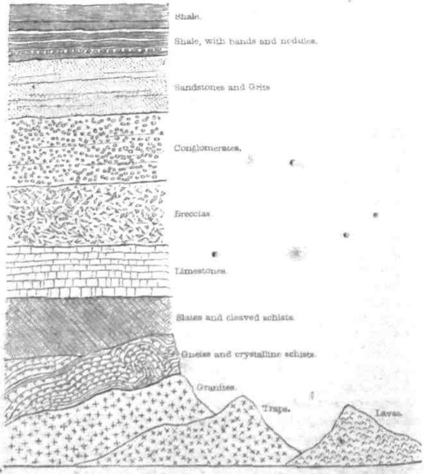
378. Being now in the field, properly equipped, and with such information as he may have gleaned by previous reading and local inquiry, the student should proceed to ascertain the *strike and dip* of the strata, taking care to ascertain the general dip, and not to be misled by oblique lamination, by cleavage, or other indications of cross structure. As with the strike and dip, so with the *direction of dykes, faults, veins*, lines of *cleavage, jointing*, and so forth, all of which are important guides to the structure

of a district, and point with certainty to the chronology of its mountain chains and axes of elevation. By laying down correctly the direction of a dyke or fault on one portion of a field, and prolonging it on his map, the student may find the same dislocation several miles distant, and be thus prepared for alterations in dip and other phenomena which might otherwise be extremely perplexing. As he proceeds in this way he will also jot down the boundaries of formations—marking only the principal outlines on his field map, and keeping all details, measurements, and figures in his note-book. We say *field map*, for it is always convenient to have one cut down in small portions for work in the field, and another preserved entire for ultimate transference and colouring. The symbols of geological surveying are not very numerous, nor are they (it is to be regretted) very closely adhered to, though the science in this respect might be greatly aided, and its acquirement facilitated. Making allowance for magnetic variation (about 24° at present), the student should always lay down the true direction; the strike of strata by parallel lines (see fig.), and their dip by arrows—straight if plane, and bent or waved if the strata are flexured and contorted. Anticlines and synclines are thus easily perceived on the map; vertical strata may



be indicated by a bold cross line; horizontal by a cipher on the shaft of a double arrow; cleavage by three sharp lines on the shaft of the arrow; faults by two faint parallel lines; and dykes by bolder ones, according to their breadth and bearing. In indicating formations on the map, the best way is to do it by colours; and though no conventional colouring is yet strictly adhered to, that now adopted by the Government Survey is the one generally followed—viz., carmine for granite, deep red for trap, and a dingy

or purplish red for volcanic; pale purple for the metamorphic, a deeper hue for the Silurian, a faint red for the Devonian, blue for the mountain limestone, dark-brown for the carboniferous, some brighter shade of red for the Permian and Trias; shades of yellow and buff for the oolites, some shade of white for the chalk, and umber for the different tertiaries. Of course, minuter divisions require a variety of shades, and these must be explained by an accompanying index of symbols. Attempts have also been made to indicate the formations by engraved tintings, cross-hatchings, stipplings, and the like; and these, in the absence of colours, may often be conveniently imitated by the pen. In sketching sections it will be found of essential service to employ



such marks to indicate at once to the eye the nature of the respective rocks and strata. Small crosses (St George's) may be used for granite; St Andrew's for trap; half crosses, or triangular

marks, for volcanic; ⊤-shaped marks for gneiss and mica-schist; a faint tinting, with cross lines, for cleaved clay-slates; dots for sandstone; larger dots for conglomerates; faint parallel and vertical touches to indicate jointed limestones; close dark tinting for shales; and so on for admixtures or combinations of these.

379. Having laid down his survey and sketched his sections, the geologist has next many deep and difficult problems to solve, some connected with the mineral composition, some with the metamorphism, and others with the origin and aggregation of the strata. In an elementary outline of this kind we can only indicate the line of research, leaving the student to gather by observation, and by his acquaintance with existing operations in nature, the many and complex phenomena connected with what may be termed the mere "physical aggregation of rock-masses." In his investigations he must endeavour to ascertain, for example, whether certain conglomerates give evidence of long-continued littoral action, or whether, from their brecciated composition, they prove a rapid and unusual process of aggregation; whether certain sandstones, from their internal structure, have been formed sub-aerially or under the water, have been aggregated along an open exposed shore, or, from their clayey laminations, have been deposited in quiet estuaries; whether certain shales have been collected as alternating river-silts, or slowly deposited in homogeneous deep-sea masses; whether certain limestones have been formed *in situ* from living shell-beds, or are littoral aggregations of drifted and broken shells; and whether others have been quiet semi-chemical precipitates, or are the mere mechanical debris of disintegrated coral reefs and minute foraminifera. He will next have to consider the internal changes or metamorphism that strata may have undergone since their deposition, and how far their texture and structure give evidence of the effects of heat, of chemical alteration, of pressure, or of any of the other agencies adverted to in par. 151. Having well weighed all the physical conditions—on which the presence of a single crystal, a pebble, a line of lamination, a ripple-marked surface, a worn shell-valve, or even the disposition of the particles which compose the mass, may often throw important light—he will next have to turn to the organic remains which the strata may enclose. And there all the known facts of botany and zoology will be necessary to the solution of his problems, and this independent of the physical questions which their presence involves. For instance, do the remains appear to have been drifted from a distance, or to have grown and lived in the sites where they are now entombed; have they been aggregated in the quiet ordinary process of life and decay,

or do they seem to have been suddenly extinguished? These and many other similar questions will at once be suggested by the appearance and positions of the fossils; and from these the philosophical inquirer will rise to the higher considerations of generic and specific distinction, analogy with existing races, the question of habitat, geographical distribution as governed by climate and other physical conditions, and, in fine, all that we know of the laws which seem to influence the locations, the variations, and mutations of vitality.

380. In making his practical investigations, the student will be materially aided by the study of an authentic collection of minerals, rocks, and fossils. To begin with, he may avail himself of such elementary collections as are sold by Professor Tennant, Mr Bryce Wright, and Mr James Gregory in London, the London agent of M. Krantz, Messrs Griffin of Glasgow and London, Mr Damon of Weymouth, Mrs Somerville of Edinburgh, Mr Doran of Dublin, and others. These, however, he will soon lay aside for a cabinet of his own collecting and arranging; and on this point we would advise him to procure a good roomy suite of drawers the moment he thinks of collecting—showing more anxiety about accommodation and the exclusion of dust than about any frivolous display of cabinet-work. The general course is to begin to collect, and then to think of a cabinet; but we can assure the student who values the perfection and distinctness of a crystal or fossil, and who knows how much such specimens suffer by the rough-handling of the uninitiated, that the better plan is to begin with the cabinet, which he will find only fills too fast for all that he would like to retain in its compartments. In a private collection it is impossible to arrange more than a few hundred *typical* specimens, and, in fact, nothing beyond this should be attempted so long as ready access can be had to the invaluable treasures of our public museums. If it is *minerals* alone that he is collecting, he will arrange them according to the classification he studies in his manual, be it that of Phillips, Hauy, Dana, or Berzelius; if it is *rocks* alone, perhaps the most instructive order is that of the formations in point of time, beginning with the granite and ending with the volcanic for the IGNEOUS, and with the metamorphic and ending with the post-tertiary for the SEDIMENTARY; and if it is *fossils* alone that he wishes to preserve, the same chronological order, tray above tray, is perhaps the most instructive and the most easily referred to. On the other hand, if he has plenty of room at his command, it is quite possible to arrange the fossils along with the rock-formations in which they occur, and even in such an arrangement to

place the mollusca, the crustacea, the fishes, &c., of each formation in some particular compartment of the trays, so as to combine a zoological with a chronological gradation. Whatever size of specimen the student adopts (and mere pigmy fragments are of very little value), he will find hammer No. 3 of great use in chipping them to shape, and the moment they are so shaped they ought to be labelled with the name, formation, locality, &c., and consigned to their compartments, and never subsequently lifted unless by the edges, and scarcely even that, save with a clean dry hand or a glove on. Occasionally, for the preservation of soft shaly specimens, it will be necessary to give them a slight coating of gum, but the less of this the better; and where the gum is apt to obscure, an additional wrapping in wadding or tissue-paper will be found to be the better preservative. On the whole, there is no great art or mystery in the formation of a geological collection—the main object being to secure fairly-selected specimens, and such as exhibit in the highest degree any particular point that may be desired. Of course, the student may not always be able to obtain the best he could desire, but let him retain what he has got till he can replace it by a better; and, above all, let him never wantonly sacrifice a duplicate—ever remembering that what may be common in one district may be rare in another, and that his rejected specimen may be the means of obtaining, in exchange, some much-coveted gem from a distant brother collector.

Difficulties and Incentives.

381. The course of practical inquiry we have sketched in the preceding paragraphs, is far from embracing all that requires to be known or followed by the working geologist. Enough, however, has been done to put the earnest and willing student on the way—the rest he must work out by his own zeal and determination; and in Geology, as in all other undertakings, a hearty goodwill—even were it to the extent of what the world calls "enthusiasm"—is more than half the victory. It is true, there are difficulties in the way—difficulties inseparable from the nature of the subject, such as the depths at which many of the strata are situated in the solid crust, the metamorphoses they have undergone since their first formation (thus increasing the difficulty of determining the agencies by which they were aggregated), the repeated upheavals and displacements of the original areas of deposition, the obscure and fragmentary condition in which many of the fossil remains are discovered, and above all,

the wide expanse over which observations must be made before we can obtain proper data for comparison and adjustment. There are also difficulties arising from the imperfections of the science, and the errors of its earlier cultivators; and the honest teacher should no more gloss over the one set of difficulties, than he should shrink from frankly owning his inability to remove the other. We refer in particular to the imperfections of geological classification; the difficulty in many cases of discriminating rocks by the nomenclature at present in use; and the daily increasing difficulty of mastering fossil species, while one and the same object figures in different works, it may be, by half-a-dozen different synonymes. With regard to the classification of the rock-systems, the student need not be discouraged. The matter will shortly right itself; and by adhering in the first instance to the great divisions about which there can be no doubt, he will soon be prepared to unravel his way among the minor subdivisions which future discoveries will either confirm or cancel. The same may be said respecting the discrimination of rock-specimens; let the student make himself familiar with the leading families, which are neither very numerous nor puzzling, and then as to minor distinctions *time and experience can be his only aids.* The difficulty attending the determination of fossil species has arisen in a great measure from the novelty and obscurity of the subject, as well as from the labour of figuring and comparing so many imperfect and fragmentary objects; but where the greatest masters are so frequently at variance and in doubt, the earnest student need neither be disheartened at his failures, nor ashamed to own his errors.

382. In a new and progressive science like Geology, which has still such a wide field of exploration before it, and which calls in the aid of so many co-relative sub-sciences, there is ample scope for the energy and industry of the most talented and enthusiastic. So vast is the field, and so varied its aspects, that there need be no jealousies nor jostlings for centuries to come. One may devote himself to its mineral forms, another to its physical problems, a third to its fossil plants, a fourth to its fossil animals, a fifth may study alone its economic products, and a sixth endeavour to find expression for the general laws which it indicates; while all may go on as one great brotherhood, united under the motto of "Head, Heart, Hand, and Hammer," in the elucidation of the history of the marvellous world we inhabit. And whether in collecting data among the hills and ravines, by the sea-cliff or in the mine, or in arranging and drawing from these data the warranted conclusion, the earnest student will find Geology at once one of the

most healthful and exhilarating, as it is intellectually one of the most expanding of human pursuits. And even where no professional object is aimed at, the man of business, the health-seeker, and holiday tourist, will find in it an endless source of recreation, peradventure of permanent instruction. Nor need the fair sex be deterred from the study, because it seems at first sight a somewhat rough and rocky one. They will discover in the forms and colours of mineral gems and metallic ores a source of attraction other than that of mere personal ornament; they will find the remains of plants and animals embalmed and preserved in a state that the most delicate need not shrink from investigating; they will find that a knowledge of the distinctive features stamped on each landscape by geological phenomena, enables them to add the truths of nature to the graces of their sketch-books; while during every walk by the sea-shore, and ramble on the hill-side, they will find in every pebble, which the feet of the ignorant would spurn from their path, something to amuse and interest even where instruction is not sought after, nor intellectual attainments prized, for the advantages they confer on their possessors. Thus, take it in no higher light than a mere recreation for an idle moment, it will be found at least an innocent and exhilarating one —one that need never interfere with the comfort of a neighbour, nor bring to the observer one pang of mortification or regret.

383. Enough, we presume, has now been stated to convince the student of Geology that the subject is one deserving his best and most earnest attention. We have done what we could, within the scope of an elementary text-book, to explain its leading facts and principles,—endeavouring rather to stimulate to further research, and point out the methods of procedure, than attempting to teach its details. And luckily for the student, these details are embodied in many inviting and accessible volumes; and more luckily for him still, the most instructive facts and important problems of the science lie in the crust beneath and around him in his own native islands,—islands, the study of which first gave character and consistency to Geology, and rescued it from the domain of ignorant hypothesis and visionary speculation. There cannot, indeed, be a finer training-field for the young geologist than the British Islands. The number of formations comprised within so small an area, their frequent upheavals and exposures, the extent of section displayed by our sea-cliffs and mountain ravines, the magnitude of our industrial operations in mines, quarries, tunnels, and railway-cuttings—laying bare so much of the earth's internal structure—are advantages peculiarly enjoyed by the British student; and though some districts cannot per-

haps vie with others in the number and distinctness of their fossil remains, that want is often more than compensated by the variety and forcible boldness of their physical demonstrations.

384. In the practical investigation of the science, the student will derive material assistance from De La Beche's *Geological Observer*,—the only work we yet possess exclusively devoted to field-procedure. He may also obtain a fair outline of its industrial bearings from the brief treatise of Mr Ansted on *Practical Geology*, in *Orr's Circle of the Sciences;* and if his calling compels attention more immediately to any department, he may glean information from some of the following sources, though it must be confessed that a competent general work on ECONOMIC GEOLOGY is still a desideratum. On Mining, the work of Mr Ansted, already referred to, Messrs Buddle and Forster *On the North of England Coal-Fields*, the treatises and papers on our Coal-Fields referred to in par. 214, the *Memoirs of the Geological Survey*, and the *Proceedings of the School of Mines*, the *Jury Reports of the Great Exhibition*, the various articles appertaining to minerals and metals in *Ure's Dictionary of Arts and Manufactures*, as also in the current edition of the *Encyclopædia Britannica*, *Phillips's Manual of Metallurgy*, and the pleasant gossiping little work of Mr Jackson *On Minerals and their Uses;* on Engineering and Building, the *Cyclopædia of Engineering*, the *Commissioners' Report on the Houses of Parliament*, the *Jury Reports of the Great Exhibition*, and papers on the Quarries of Scotland in the *Transactions of the Highland Society;* on Agriculture, the *Lectures* of the late Professor Johnston, the papers of Mr Trimmer, Mr Nesbitt, and others, in the *Journal of Agriculture*, and various of the Highland Society's prize-essays and reports; while on the subject of Landscape, some available hints may be gathered from Mr Ansted's *Treatise*, Ruskin's *Modern Painters*, and the respective editions of Professor Phillips's *Manual of Geology*. On the whole, the practical applications of the science, though well known and of paramount importance, have been less discussed or methodically treated than its theoretical aspects, and the student must be contented in the mean time to glean from scattered sources what he might have fairly anticipated from the pages of some compendious and trustworthy volume.

GLOSSARY.

A.

ABERRANT (Lat. *ab*, and *erro*, I wander from). — Applied in natural history classification to those species ("aberrant species") which differ widely from the type of the natural group or family to which they belong.

ABIETITES (Lat. *abies*, the fir-tree).—A genus of coniferæ occurring in the wealden and greensand. The genus has been founded chiefly on the cones, which are often found in great perfection—these cones being composed of scales that terminate in a point, and not in a rhomboidal disc, as in *Pinus*, which see.

ABNORMAL (Lat. *ab*, and *norma*, a rule). —Without rule or order; irregular; not occurring in the usual order, or according to that which is considered as the natural law.

ABRASION (Lat. *ab*, from, and *radere*, to rub or scrape).—The operation of wearing away by external rubbing or friction; hence certain abraded rock-surfaces. Currents of water laden with sand, shingle, and other rock-debris, drifting icebergs, and descending glaciers, are the chief abrading agents in nature.

ACANTHODES (Gr. *akantha*, a spine or thorn).—One of Agassiz's genera of ganoid fishes, occurring in the devonian and lower coal-measures, and characterised by the strong thorn-like spines with which all the fins are furnished. The dorsal and anal fins are single—the latter being placed somewhat in advance of the former.

ACEPHALOUS (Gr. *a*, without, and *kephalè*, head).—Applied to those mollusca, like the oyster and scallop, which have no distinct head, in contradistinction to the *encephalous*, or those with a distinct head. The class Acephala comprehends most of the bivalve molluscs, and several which are destitute of shells.

ACICULAR (Lat. *acicula*, a little needle). —Mineral crystals occurring in needle-like prisms or prickles, as actinolite, are said to be acicular.

ACIDULOUS and ACIDULATED.—Slightly acid, or sub-acid; applied to certain waters and springs.

ACRODONT (Gr. *akros*, the summit, and *odous*, tooth).—A term applied by Professor Owen to those scaly or loricated saurians whose teeth are anchylosed to the summit of the alveolar ridge. *See* Thecodont.

ACROGENOUS (Gr. *akros*, the top, and *ginomai*, I am formed).—Applied to those cryptogamic plants which increase by growth at the summit, or growing point, as the tree-ferns

ACTINOCRINUS (Gr. *aktin*, a thorn or prickle).—A genus of encrinites, found chiefly in the carboniferous limestone, and distinguished by the thorn-like side-arms or processes which project from the main column or stalk at irregular distances.

ACTINOLITE (Gr. *aktin*, a ray or thorn, and *lithos*, stone).—A mineral and rock of the granitic group, composed of radiated or thorn-like crystals of a dark or greenish hue, and closely allied to hornblende.

ADIPOCERE (Lat. *adeps*, fat, and *cera*, wax).—A waxy, fatty substance into which animal matter is converted when buried in moist earth, or when subjected to long immersion in water. It is chiefly *margarate of ammonia*, and is obviously generated by the reaction of the ammonia upon the margarine and oleine of the animal substances from which it is produced.

ÆPYORNIS (Gr. *aipus*, immense, and *ornis*, bird).—An extinct cursorial bird of gigantic dimensions, the eggs and a few scattered bones of which have been recently discovered in the alluvial deposits of Madagascar. The egg has about six times the capacity of that of the ostrich, but the bones would seem to indicate a bird little more than twice the size of its African congener.

AFTER-DAMP. — Another name for "choke-damp" or carbonic acid, as occurring in mines after an explosion of "fire-damp," or light carburetted hydrogen.

AGATE (*said to be from the river Achates, where fine varieties occur*).—A mixed siliceous mineral found in veins, nodules, and geodes. The geodes often consist of alternating bands or deposits of carnelian, calcedony, jasper, opal, quartz, &c. ; hence the varieties of the mineral are known by such names as ribbon-agate, fortification-agate, brecciated-agate, moss-agate, &c.

AGNOSTUS (Gr. *agnostos*, unknown, obscure).—A genus of minute trilobites supposed to be characteristic of the lowest Silurian zones.

AIGUILLE (Fr., a needle).—Applied in physical geography and geology to the sharp serrated peaks of lofty mountains. *It is generally the crystalline rocks*, such as gneiss, quartz, and the like, that weather into the *aiguille*, or needle-top.

ALABASTER (Gr. *alabastron*).—A white semi-transparent granular or massive variety of gypsum, or sulphate of lime. *It is a mineral of common occurrence in* secondary and tertiary formations (Cheshire, Montmartre near Paris, Montaiout in Italy, &c.), and being readily turned by the lathe, is manufactured into statuettes, vases, and other domestic ornaments ; hence perhaps the term *alabastron*, an ink or perfume vase.

ALBITE (Lat. *alba*, white).—A species of *felspar of a greyish-white or milky*-white colour, composed of silex 70.5, alumina 19.5, soda 9.5, and traces of lime and oxide of manganese. It is also known as *Cleavelandite*.

ALBUM GRÆCUM.—The whitish hardened excrement of dogs, wolves, hyænas, &c., feeding on bones. *It consists chiefly of* the earth of bones or lime, in combination with phosphoric acid. That of the hyæna occurs abundantly fossil in the bone-caves of Europe.

ALGÆ (Lat. *alga*, sea-weed).—Cellular aquatic plants, mostly of marine habitat.

ALLUVIUM (Lat. *luere*, to wash, and *ad*, together).—Matter washed or brought *together by the ordinary operations of* water is said to be *alluvial*, and the soil or land so formed is spoken of as *alluvium*. The soil of most of our river-plains, which have been the sites either of lakes or of estuaries, is alluvial. Our straths, carses, dales, holmes, and meadow-lands, are chiefly alluvial. *See* Diluvium.

ALUM (Lat. *alumen*, Gr. *hals*, *halos*, salt). —*Alum is a double salt, the sulphate* of alumina and potash, the crystals of which contain nearly 50 per cent of water. Alum is chiefly manufactured from certain shales, as those of the lias in Yorkshire, of the coal in Lanarkshire, &c. ; hence *alum-shale*, *aluminite*, *alum-stone*, &c.

ALUMINA.—*The pure plastic principle of* clay, which is usually a silicate of alumina. Alumina is, in fact, an oxide of the metal aluminum, consisting of aluminum 12, and oxygen 8.

AMBER (Arabic).—A well-known fossil gum, or gum-resin, usually found in connection with tertiary lignites, and associated with certain coniferous trunks and branches (*Pinus succinifer*, the amber pine), of which it is supposed to have been the exudation. It is hard, rather brittle, easily cut, of various shades of yellow, and semi-transparent. It is very light, is highly electric, and burns, like other hydrocarbons, with much smoke and flame.

AMBLYPTERUS (Gr. *amblys*, blunt, and *pteron*, fin).—Literally "broad or blunt fin ;" a genus of ganoid fishes belonging to the *Lepidoid* family, occurring in the carboniferous formation, and characterised, as the name implies, by their very large and wide fins, composed of numerous rays.—See fig.

AMETHYST.—Quartz or rock-crystal coloured by iron and manganese ; or, as recently affirmed, by some peculiar hydro-carbon. The amethyst is a transparent gem of a purple or violet-blue colour : it is sometimes naturally colourless, and may at any time be deprived of its colour by the action of heat. Some derive the name from its colour, *which resembles wine mixed with* water ; while others think it obtained its name (Gr. *a*, without, and *methystes*, drunkard) from its supposed virtue of preventing intoxication, hence worn by topers as an amulet.

AMIANTHUS (Gr. *a*, without, and *miaino*, to soil).—*This term, though often used* as synonymous with *asbestus*, properly includes only the varieties which occur *in delicate silky fibres*. *See* Asbestus.

AMMONITE.—The fossil shell of a numerous and varied family of cephalopodous mollusca coiled in a plain spiral, and chambered within like the existing nautilus ; so called from the resemblance of the shell to the horns on the statue of Jupiter Ammon. "*Cornu ammonis*," "Whitby snakes," and "snake-stones," are obsolete synonymes.—See figs.

AMORPHOUS (Gr. *a*, without, and *morphè*, form).—Applied to minerals and rock-masses which have no regular or determinate form ; void of structure.

AMORPHOZOA (Gr. *a*, without, *morphè*, form, and *zoon*, an animal).—The lowest class of the animal kingdom, con*taining the sponges and their allies* : so called from the want of regular organic structure in their parts.

AMPHITHERIUM (Gr. *amphi*, implying doubt, and *therion*, a wild beast).—An insectivorous quadruped of the oolitic epoch; so termed from the doubts as to its true affinity—marsupial or placental.—See fig., Oolitic System.

AMYGDALOID (Gr. *amygdalon*, an almond, and *eidos*, form).—This term is applied to certain igneous rocks containing small almond-shaped vesicular cavities, either partially or entirely filled with agate, jasper, calc-spar, and other minerals. These minerals being of a different colour from the mass of the rock in which they are imbedded, look like almonds in a cake; hence the term *amygdaloidal*.

ANALCIME (Gr. *a*, without, and *alkimos*, strong). — A zeolitic mineral found abundantly in trappean rocks: so called from its feebly electric properties. Same as Cubizite.

ANALOGUE (Gr. *ana*, with, and *logos*, reasoning).—An object that resembles another, or which performs *a similar function*; as the dermal expansions of the bat and the wing of the bird, which are *analogous* but not *homologous*.

ANGIOSPERMS (Gr. *angeion*, a vessel, and *sperma*, seed).—Plants whose seeds are encased, or in seed-vessels; in contradistinction to *gymnosperms*, which see.

ANHYDROUS (Gr. *a*, without, and *hydor*, water).—Without water; applied to minerals which do not contain water as an ingredient. Without water of crystallisation.

ANNELIDA (Lat. *annellus*, a little ring). —Annelids; one of the classes of the animal kingdom, having their bodies formed of a great number of small rings like the earth-worm, a double ganglionated nervous cord, and red blood.

ANNULOSA (Lat. *annulus*, a ring). —A designation given by M'Leay to the *articulata*, in allusion to their ringed or annulated bodies. The term in this sense is seldom employed by other zoologists.

ANOPLOTHERIUM (Gr. *a*, without, *oplon*, weapon, and *therion*).—A fossil pachydermatous quadruped from the Paris tertiaries, and so called from being destitute of any organs of defence, as tusks, claws, or horns. The genus seems to stand intermediate between the rhinoceros, hog, and horse, and to partake in some respects of the characters of the camel.—See fig., Tertiary System.

ANTHOLITES (Gr. *anthos*, a flower, and *lithos*, stone).—The general term for the fossil inflorescence of plants, or rather the impression of their flowers. They are found from the carboniferous upwards.

ANTHRACITE (Gr. *anthrax*, carbon).—A variety of coal almost wholly deprived of its bitumen. It may be regarded as natural coke or charcoal, formed by subterranean or chemical heat. Ordinary bitumiuiferous coal is often found converted into a kind of coke by the contact of igneous rocks; and in this way many anthracites may have originated.

ANTHRACOTHERIUM (Gr. *anthrax*, coal, and *therion*, wild beast).—A fossil pachydermatous animal found in lignitic tertiaries.

ANTICLINAL (Gr. *anti*, on opposite sides, and *clino*, I bend).—Applied to strata which dip in opposite directions from a common ridge or axis—like the roof of a house—and form what is termed an "anticline" or "saddle-back."

ANTISEPTIC (Gr. *anti*, opposed to, and *sepo*, I putrefy). —Substances which, like salt and tannin, prevent putrefaction in animal and vegetable substances, are said to be antiseptic.

APATITE (Gr. *apatè*, deceptive).—A calcareous mineral composed of 55.75 lime, and 44.25 phosphoric acid; hence known as phosphate of lime. There are several varieties, both massive and crystallised, distinguished by their fracture, &c.—as foliated apatite, conchoidal apatite, and phosphorite having an uneven fracture.

APIOCRINITE (Gr. *apion*, a pear, and *encrinite*).—A genus of encrinite distinguished by its pear-shaped body, and peculiar to the oolite and chalk systems.

ARAUCARITES.—A term employed to designate those fossil trunks and stems whose structure is identical with that of the living Araucariæ, having the same kind of medullary rays, and the woody fibre studded with discs or areolæ, which are polygonal, often hexagonal, and disposed in several alternating series.

ARCHÆOCIDARIS (Gr. *archaios*, ancient, and *cidaris*, a turban; hence the "sea-egg," from its turban-shape).—A genus of sea-urchins or cidaris, occurring in carboniferous and permian strata, and characterised by their small hexagonal plates and long spines, which in some species are smooth, and in others notched and sharply denticulated.

ARCHÆONISCUS (Gr. *archaios*, ancient, and *oniscus*, wood-louse).—A genus of fossil Isopods (equal-footed crustaceans) occurring in the Purbeck or uppermost oolitic strata, and so termed by the Rev. P. B. Brodie, from their close resemblance to the common wood-louse.—See fig., Oolitic System.

ARCHEGOSAURUS (Gr. *archegos*, beginning, and *saurus*, lizard). — Literally "primeval lizard;" a reptile of the carboniferous era, having, according to Owen and Goldfuss, a near alliance to the *proteus*, *lepidosiren*, and other

perennibranchiate reptiles of the present day.

ARENACEOUS (Lat. *arena*, sand).—Rocks composed of grains like sand, or containing sand in any notable degree, are said to be *arenaceous*.

ARGILLACEOUS (Lat. *argilla*, clay).—Applied to all rocks or substances composed of clay, or having a notable proportion of clay in their composition. Argillaceous rocks are readily distinguished by the peculiar odour they emit when breathed on.

ARTESIAN WELLS.—Wells sunk by boring perpendicularly through the solid strata, and in which the subterranean waters rise to the surface or nearly so—a method long known and practised in the province of Artois, the ancient *Artesium*, in France. Many of the Artesian wells in London and Paris are of great depth—that in the Plain of Grenelle being about 1800 feet deep, bore 10 inches in diameter, discharge 517 gallons per minute, and temperature of water 82° Fahr.

ARTICULATA (Lat. *articulus*, a joint).—One of the four great divisions of the animal kingdom, including all the invertebratâ with jointed bodies—as insects, crustacea, spiders, worms, &c.

ASAPHUS (Gr. *asaphès*, obscure). — A genus of trilobites, and so called from the obscurity which long rested on the true nature of these crustacea, which were at first confounded with insects, and termed *Entomolithus*.—See fig.

ASBESTUS (Gr. *a*, without, and *sbestos*, consumable or extinguishable). — A fibrous, flexible variety of hornblende or augite, used by the ancients in the manufacture of an incombustible cloth; hence its name *asbestos*, unconsumable. There are several varieties, as *amianthus*, *mountain-cork*, *mountain-wood*, *mountain-leather*, &c.

ASPHALT (Gr. *asphaltos*).—This term is usually applied to a black, hard, brittle, and glossy variety of bitumen, which is distinguished from other varieties chiefly by its more difficult fusibility, and by its fracture being clean, conchoidal, and vitreous. It occurs in formations of all ages, and is associated with different kinds of rocks, though most frequently in connection with sandstones and limestones.

ASTERACANTHUS (Gr. *aster*, star, and *akantha*, spine).—Literally "starry spine;" a genus of ichthyodorulites, so termed from having their surfaces richly ornamented with star-like tubercles. These fin-rays (often of large size) are common in the lias, oolite, and wealden.

ASTEROIDEA (Gr. *aster*, a star, and *eidos*, form).—Applied to starfishes. An order of echinoderms with one opening to the alimentary canal, and of rayed or star-like structure.

ASTEROLEPIS (Gr. *aster*, a star, and *lepis*, a scale). — Literally "star-scale;" a gigantic ganoid fish of the old red sandstone, so named from the stellate markings on the dermal plates of the head, which are of great size, and form a strong expanded buckler, the orbits of the eyes being situated near the anterior border.

ASTEROPHYLLITES (Gr. *aster*, and *phyllon*, a leaf). — An assemblage of plants found abundantly in the coal-measures, lias, and oolite; and so called from the star-like whorls of the linear leaves (verticellate leaves) which surround the jointed stems, as in equisetum, hippuris, and the like.—See fig., Carboniferous System.

ATOLLS.—The name given to coral islands of an annular form—that is, consisting of a circular belt or ring of coral, with an enclosed lagoon.

AUGITE (Gr. *augè*, lustre).—A mineral entering largely into the composition of many trap and volcanic rocks. In composition it is closely allied to hornblende, but differs in the form of crystal—is less siliceous, and of greater specific gravity. Known also as *Pyroxene*.

AURIFEROUS.—(Lat. *aurum*, gold, and *fero*, I yield).—Yielding or containing gold; applied to rocks and veins containing the precious metal, as "auriferous veins," "auriferous sands," &c.

AVALANCHES (Fr. *avalanges*, *lavanches*). —Accumulations of snow, or of snow and ice, which descend from precipitous mountains, like the Alps, into the valleys beneath. They originate in the higher regions of mountains, and begin to descend when the gravity of the mass becomes too great for the slope on which it rests, or when fresh weather destroys its adherence to the surface. Avalanches are usually distinguished as Drift, Rolling, Sliding, and Glacial. *Drift*, are those caused by the action of the wind on the snow while loose and powdery; *rolling*, when a detached piece of snow rolls down the steep, licks up the snow over which it passes, and thus acquires bulk and impetus as it descends; *sliding*, when the mass loses its adhesion to the surface, and descends, carrying everything before it unable to resist its pressure; and *glacial*, when masses of frozen snow and ice are loosened by the heat of summer and precipitated into the plains below.

AVICULA.—(Lat., a little bird).—A free unequal-valved shell, fixing itself by a byssus, the hinge without a tooth, and rather callous, valves somewhat gaping near the beak. It is the type of the AVICULIDÆ, which embraces

avicula, *posidonomya*, *aviculopecten*, *gervillia*, *perna*, *inoceramus*, and *pinna*.

AVICULOPECTEN.—The avicula-like pecten, an extensive genus of monomyarian bivalves peculiar to the carboniferous limestone, and often so well preserved that even the colours of the living shell are retained. The form in the several species is more elongated than in pecten; valves slightly unequal, and hinge without a tooth.—See fig., Carboniferous System.

AXIS (Lat. *axis*, a pole or axle-tree).—A word used largely and variously in natural science: applied to the line about which objects are symmetrical, along which they are bent, around which they turn, or to which they have some common relation; hence "vertebral axis," "axis of elevation," "synclinal axis," &c.

AYMESTRY LIMESTONE.—The middle member of the Ludlow group of silurian strata; so named from the village of Aymestry, where it is exposed.

AZOIC (Gr. *a*, without, and *zoë*, life).—Applied to the lowest strata which have yet yielded no traces of life. Used by many as synonymous with Hypozoic, Non-fossiliferous, and Metamorphic, which see.

B

BACK.—A miner's term for "joint;" hence "backs and cutters," applied to jointed structure.

BACULITE (Lat. *baculus*, a staff).—A straight-chambered tapering shell of the chalk epoch; so named from its straight staff-like shape. It consists of numerous chambers, divided by transverse sinuous septa, the outer chamber being much larger than the others.—See fig., Cretaceous System.

BALANITE (Lat. *balănus*, a barnacle).—The name given to fossils of the barnacle family, whose shells in general consist of six principal valves, arranged in conical form. The cirripeds or barnacles are scarcely, if at all, known till the commencement of the oolitic era.

BARYTES (Gr. *barys*, heavy).—Heavy spar, or sulphate and carbonate of baryta: so called from its great specific gravity, which is about 4, thus being the heaviest of all the known earths.

BASALT (Gr. and Lat. *basaltes*, but of unknown origin, some deriving it from an Ethiopian word, *basal*, iron, and others from *hals*, salt, in allusion to its crystallised or columnar structure).—An abundant member of the trappean group, close-grained, hard, usually black, and frequently columnar; the columns regular and jointed.

BASIN.—Any concave surface of strata dipping toward a common axis or centre is termed a *basin*, *trough*, or *syncline*. The tertiary rocks often occupy limited areas, and dip in this way; hence "London basin," "Paris basin," &c.

BASSET or BASSET EDGE.—A miner's term for the outcrop or surface edge of any inclined stratum. *See* Outcrop.

BATHYMETRICAL (Gr. *bathys*, deep, and *metron*, a measure).—Applied to the distribution of plants and animals along the sea-bottom, according to the depth of the zone (measuring from the shore) which they inhabit.

BEETLE-STONE.—A name given to coprolitic nodules of ironstone, &c., from the fanciful resemblance of the coprolite, and its radiating films of calc-spar, to the body and limbs of a beetle. *See* Septaria.

BELEMNITE (Gr. *belemnon*, a dart).—An abundant cretaceous and oolitic fossil, apparently the internal bone or shell of extinct cephalopods allied to the squid and cuttle-fish. Belemnites are usually found as straight, solid, tapering fossils, but occasionally the upper or chambered portion is attached, and even, in some instances, the colouring-matter of the ink-bag has not been altogether obliterated. The *pen* of the common squid is a slender, insignificant organ compared with the belemnite and its extinct congeners.—See figs., Oolitic System.

BELLEROPHON.—(A fanciful appellation from Bellerophon, a fabulous hero of Grecian antiquity.) An extensive genus of fossil nautiloid shells, consisting of a single chamber, like the living argonaut. They occur in the silurian, devonian, and carboniferous strata—upwards of twenty species being met with in the mountain limestone. The *Bellerophontidæ* are most generally regarded as belonging to the *Heteropoda*, and allied to the glass-shell (*carinaria*); though by some they are considered to be a simple form of *cephalopod*.—See fig., Carboniferous System.

BERG-MAHL (Swedish).—Literally mountain-meal, a recent infusorial earth of a whitish colour and mealy grain, said to be eaten by the Finns and Laplanders in seasons of great scarcity; hence the name.

BERYL.—A lapidary's term for the less brilliant and colourless varieties of the emerald—this want of colour arising from the absence of chromium, which

gives to the emerald its deep rich green.

BERYX.—A genus of ctenoid fishes belonging to the perch family, the living species of which inhabit the seas of Australia. A number of species have been obtained from the chalk of the south-east of England, where it is one of the most common ichthyolites.—See fig. under Chalk Formation.

BEYRICHIA (after M. Beyrich).—A genus of minute phyllopodous crustaceans belonging to the family *Limnadiadæ*, of which the existing Limnadia has been taken as the type. They are bivalved, and their minute three-lobed-like coverings occur in profusion both in lower and upper silurian strata.

BITUMEN (Gr. *pitus*, the pitch-tree).—Mineral pitch or tar. As a class, the bitumens are inflammable mineral substances, which burn like pitch, with much smoke and flame. Naphtha, petroleum, and asphalt are familiar examples; and substances impregnated with them, or which yield them on distillation, are said to be *bituminous*, though *bituminiferous* would be the more appropriate term.

BITUMINOUS (*see* Bitumen).—Containing bitumen, or having the properties of bitumen; *bituminiferous*, yielding bitumen naturally or by distillation; *bituminated*, impregnated, or prepared with bitumen; *bituminise*, to prepare or coat with bitumen; and *bituminisation*, the natural process of being converted into bituminous matter

BLACK-BAND.—A Scotch miner's term for those ironstones which contain coaly matter sufficient to calcine the ore without any artificial addition of fuel. *See* Ironstone.

BLACK-LEAD.—A familiar term for graphite, from its resemblance to the metal lead; called also, for the same reason, *plumbago*.

BLENDE (Ger. *blenden*, to dazzle).—A term applied by mineralogists to several minerals having a peculiar lustre or glimmer—as hornblende, zinc-blende, &c.; but now chiefly applied to a metallic ore of zinc, the sulphuret or black-jack of the English miner.

BLUFFS.—An American term for high banks presenting a precipitous front to the sea or a river.

BOLE (Gr. *bolos*, a clod).—Applied to a friable clayey shale or earth, usually highly coloured with oxide of iron.

BOTHRODENDRON (Gr. *bothros*, a pit or cavity, and *dendron*, tree).—A genus of coal-measure stems with dotted surfaces, and distinguished from sigillaria and stigmaria by two opposite rows of deep oval concavities, which appear to have been made by the bases of large cones or seed-bracts.—See fig., Carboniferous System.

BOTRYOIDAL (Gr. *botrys*, a bunch of grapes, and *eidos*, form).—Applied to certain concretionary forms, as those occurring in the magnesian limestones of Durham, the hæmatites of Westmoreland, &c., which resemble clusters of grapes.

BOULDERS.—Any rounded or water-worn blocks of stone, which would not from their size be regarded as pebbles or gravel, are termed *boulders*. The name, however, is generally restricted to the large water-worn and smoothed blocks found imbedded in the clays and gravels of the "drift formation."

BRACHIOPODA (Gr. *brachys*, an arm, and *pous*, *podos*, a foot).—A numerous order of mollusca, including equal and unequal valved genera, with spiral arm-like organs on each side the mouth, *e.g.*, terebratula, spirifer, &c.

BRECCIA (Ital., a crumb or fragment).—A term applied to any rock composed of an agglutination of angular fragments, as "volcanic breccia," "osseous breccia," &c. A *breccia* or *brecciated rock* differs from a conglomerate in having its component fragments irregular and angular, whereas the pebbles of the latter are rounded and water-worn.

BROWN-COAL.—Another name for tertiary lignite, in allusion to its colour, as distinguished from the clear shining black of true coal.

BRYOZOA (Gr. *bryos*, moss, and *zoon*, an animal).—This term embraces all the minute mollusca which inhabit compound structures, and which were formerly regarded as zoophytes or corallines. The term refers to their branched and moss-like aggregation. Same as *Polyzoa*, which see.

BUNTER (Ger. variegated).—The German term for the new red sandstone, in allusion to its variegated colour.

BURRH-STONE or BURR-STONE.—A porous siliceous stone of a whitish or cream colour, obtained from the tertiary beds of the Paris basin, and used in the manufacture of millstones.

C

CAIRNGORM.—A yellow or amber-coloured variety of rock-crystal, so called from being found in great perfection at Cairngorm, Aberdeenshire.

CALAMITES (Lat. *calamus*, a reed).—A genus of fossil stems occurring abundantly in the coal-measures, and so termed from their resemblance to gi-

gantic reeds. Their true affinities, however, are not well known; and all that can as yet be said of them is, that they are tall, hollow, articulated stems, furnished with leaves or branches at the joints, possessing a distinctly separated wood and bark, and readily disarticulating at the *nodi* or joints.—See fig., Carboniferous System.

CALCAIRE GROSSIER (Fr., literally coarse limestone). — An important member of the lower tertiaries of the Paris basin.

CALCAREOUS (Lat. *calx*, *calcis*, lime).—Composed of, or containing a considerable portion of lime.

CALCEDONY (Lat. *calcedonius*, found at Calcedon).—A semi-transparent siliceous mineral, allied to the opal and agate, and often found associated with them in geodes and vein-bands.

CALCEOLA (Lat., a little shoe or slipper).—A fossil brachiopod, so called from its under or ventral valve, which is flatly conical, or compressed like the point of a shoe, and fitted with an opercular or lid-like upper valve. It is characteristic of the middle devonian period, and so abundant in the schists underlying the Eifel limestone, that these are known to German geologists as "Calceola-schiefer."—See fig., Devonian System.

CALYMENE (Gr. *kekalymmenè*, concealed, obscure).—A genus of trilobites, deriving its name from the obscurity which long hung over the real nature of these crustaceans.—See fig., Silurian System.

CAINOZOIC (Gr. *kainos*, recent, and *zoë*, life). — The upper stratified systems holding recent forms of life, as distinguished from *mesozoic* and *palæozoic*.

CALP.—A provincial Irish term for an impure argillaceous limestone, which occurs between the two great bands of the carboniferous limestone as developed in Ireland; hence the phrases "calp-shales," "calp-slates," &c.

CAMBRIAN and CUMBRIAN.—Terms applied by Professor Sedgwick to the strata which lie beneath the true silurian system, from their occurring largely in Wales (Cambria) and in Cumberland.

CANNEL-COAL.—A compact, brittle, jet-like variety of coal, sonorous when struck, breaks with a less or more conchoidal fracture, and does not soil the fingers when handled. So called from the candle-like light it yields when burning.

CARADOC SANDSTONE.—The upper member of the lower silurians, typically developed in the Caradoc hills.

CARBONACEOUS (Lat. *carbo*, coal). — Coaly; applied to rocks containing abundant traces of fossil carbon, or vegetable debris; hence carbonaceous shales, sandstones, &c.

CARBONIFEROUS (Lat. *carbo*, coal, and *fero*, I yield).—Coal-yielding or coal-bearing. The term is usually applied to that system of palæozoic strata from which our chief supplies of coal are obtained.

CARNELIAN (Lat. *caro*, *carnis*, flesh).—Applied originally to a flesh-coloured variety of calcedony, but now a lapidary's term for the more transparent varieties, whether brown, red, yellow, or white.

CARPOLITHES (Gr. *karpos*, fruit, and *lithos*, a stone).—The general term for fossil fruits, such as those that occur in the tertiary clays of the London basin, in the coal shales of Newcastle, &c.

CATACLYSM (Gr. *kataklysmos*, inundation).—Any violent flood or inundation is so termed; deluge; debacle.

CATENIPORA (Lat. *catena*, a chain, and *pora*, a passage).—Chainpore coral, a species peculiar to palæozoic strata.

CAULOPTERIS (Gr. *kaulos*, stem, and *pteris*, fern). — Literally tree-fern; a genus of stems or trunks found in the coal-measures, and regarded by Dr Lindley as decidedly the stems of tree-ferns. See fig., Carboniferous System.

CEPHALASPIS (Gr. *kephalè*, head, and *aspis*, buckler).—A fish of the old red sandstone; so called from the buckler shape of its head, the bones of which seem to have been united into a single piece or case. The body also seems to have been protected by osseous bands, leaving the tail, pectorals, and other fins free, as in the existing trunk-fish.—See fig., Devonian System.

CEPHALOPODA (Gr. *kephalè*, head, and *pous*, *podos*, foot).—The highest class of mollusca, with foot-like organs around the mouth or head, as the cuttle-fish and nautilus.

CERATIOCARIS (Gr. *keration*, a pod, and *kăris*, shrimp). — An upper silurian crustacean, whose exact affinities are unknown, but whose form apparently connects it with *apus* and *dithyrocaris*. It derives its name from its large, finely-striated, pod-like, bivalved carapace, which has frequently been mistaken for a bivalve shell.—See fig., Silurian System.

CERATITES (Gr. *keras*, a horn).—A genus of triassic chambered cephalopods, distinguished from the ammonites of the superincumbent lias and oolite, by the absence of foliated sutures—the descending lobes terminating in small denticulations pointing inwards.

CESTRACIONIDÆ, CESTRACIONTS (Gr. *kestron*, a pike, a kind of fish, so called from its formidable teeth).—A sub-family of sharks, occurring in all formations from the silurian upwards, and now represented by a solitary species, the *Cestracion Phillippi*, or Port

Jackson shark. The character of the cestracionts is marked by the presence of large polygonal, obtuse, enamelled teeth, covering the interior of the mouth with a kind of tesselated pavement.

CHALYBEATE (Gr. *chalybs*, iron). — Impregnated with iron; applied to springs containing iron.

CHEIRACANTHUS (Gr. *cheir*, the hand, and *akantha*, a thorn).—Literally "thorny hand," in allusion to the spine that protects the pectoral fins. The *cheiracanthus* belongs to the Acanthod family; was a small, slim fish, covered with minute, lozenge-shaped scales, each having a slight median ridge; and armed in all its fins with defensive spines. Differs from *acanthodes* in having the dorsal situated in advance of the anal fin.—See fig., Old Red Sandstone.

CHEROPOTAMUS (literally river-hog).—A pachydermatous quadruped from the Paris tertiaries, very closely related to the hogs; hence the name.

CHERT. — A mixed siliceous rock, or rather flinty portions occurring in other rocks, as limestone. A limestone so siliceous as to be worthless is said to be "cherty."

CHIASTOLITE (Gr. *chiastos*, marked with the letter χ, or cleft, and *lithos*, stone). — A mineral whose crystals are arranged in long four-sided prisms, and often cross and lie over each other in certain clay-slates like the letter χ.

CHLORITE (Gr. *chloros*, greenish). — A mineral occurring in the granitic and metamorphic rocks, often in thin scales like mica, more frequently disseminated through or coating the laminæ of the schists in which it occurs—*e. g.*, chlorite schist.

CHOKE-DAMP.—A miner's name for carbonic acid gas, as distinct from *fire-damp*, or light carburetted hydrogen. *See* After-damp.

CHRONDRITES (*chondrus*, a species of seaweed).—Fossil marine plants of the chalk and other formations; so called from their resemblance to the existing *chondrus*.—See fig., Silurian System.

CLAYSTONE and CLAYSTONE-PORPHYRY. —Felspathic igneous rocks of a tough but earthy texture.

CLEAVAGE.—A fissile structure not coincident with (often at right angles to) the original lamination or bedding of the strata in which it occurs. Prevalent in clay-slates; hence their peculiar fissility.

CLINKSTONE. — A species of felspathic greenstone; so called from its ringing sound under the hammer. Same as *Phonolite*.

CLYMENIA (Gr. *Clymenê*, a sea-nymph). —A genus of nautiloid shells peculiar to devonian strata, in which upwards of 40 species have been detected. In the clymenia the septa of the chambers are simple or slightly lobed, and the siphuncle is internal instead of dorsal, as in the ammonites; hence the occasional synonyme of *Endosiphonites*.—See fig.

COCCOSTEUS (Gr. *kokkos*, a berry, and *osteon*, a bone), literally "berry-bone;" a fish of the old red sandstone, and so termed from the small berry-like tubercles with which the plates of its cranial buckler and body are thickly studded. In general appearance *coccosteus* resembles *pterichthys*, but wants the arm-like appendages, and is usually much larger—ranging in the Caithness flagstones from a few inches to two feet in length.—See fig., Old Red Sandstone System.

COLOLITES (Gr. *kolon* and *lithos*). — A name given to certain tortuous and convoluted intestinal-like masses and impressions, supposed to be either the petrified intestines of fishes, or the contents of their intestines, still retaining the form of the tortuous tube in which they were lodged. In most instances, however, these so-called *cololites* are undoubted worm - casts, like those thrown up on sandy shores by the common lob-worm.

COLOSSOCHELYS (Gr. *kolossos*, a statue of enormous size, and *chelys*, a tortoise).— The generic term given by Dr Falconer to the bones and portions of the carapace of a tortoise of gigantic dimensions, discovered by him and Captain Cantley in the upper tertiaries of the Sevâlik hills in India. The remains indicate a length of 12 or 14 feet.

CONCRETIONARY (Lat. *con*, and *cretus*, grown together).—Nodules like those of chert or ironstone, the grains and spherules of oolite, and the grape-like clusters of the magnesian limestone, are termed concretions, as formed by a molecular aggregation distinct from *crystallisation*.

CONFERVITES.—Fossil plants apparently allied to the aquatic confervæ.

CONFORMABLE. — Strata or groups of strata lying one above another in parallel order.

CONGLOMERATE (Lat. *con*, together, and *glomerare*, to gather in round heaps).— Rocks composed of consolidated gravels; known also as *pudding-stones*, from the resemblance of the pebbles in the mass to the fruit in a plum-pudding.

CONIFERÆ. — Cone-bearing: applied to the pine tribe, whose seed occurs in cones, as the fir, yew, araucaria, &c.

CONULARIA (Lat. *conulus*, a little cone). —A genus of pteropod shells, so called from their tapering conical outline. Conularia is four-sided, straight, tapering, the angles grooved, and the sides

striated transversely, as if the thin shell had been divided by numerous septa. Several species are found in the silurian, devonian, and carboniferous formations. — See fig., Carboniferous System.

COPPERAS (Ger. *kupfer-wasser*). — The familiar term for sulphate of iron. The sulphate of copper occurs in blue, and the sulphate of iron in green crystals; hence apparently the term copperas. It is prepared by moistening the pyritous shales (sulphurets of iron) which are found abundantly in the coal-measures, &c., and exposing them to the air, when oxidation takes place, and the sulphuret is converted into the sulphate of iron, which is subsequently dissolved and evaporated, to procure it in the crystallised state.

COPROLITE (Gr. *kopros*, dung, and *lithos*, stone).—Petrified excrements, or dung-stone. Coprolites are found in all the secondary and tertiary strata, and appear to be the voidings chiefly of saurians and sauroid fishes. In many instances they contain fragments of scales, shells, &c., the undigested portions of the prey of these voracious animals. Many specimens exhibit on their surfaces the corrugations and vascular impressions of the intestines; and masses of coprolites have been detected *in situ* within the ribs of liassic ichthyosauri.

CORAL (Gr. *korallion*).—The comprehensive term for all calcareous structures secreted by the marine asteroid polypes or zoophytes. *Coralloid*, having the appearance or structure of coral.

CORAL-REEF.—The term applied to the aggregate mass of coral structures. The zoophytes being gregarious and in myriads, these structures are spread over vast areas of the southern seas in long narrow ledges or "barrier-reefs," and in circular ledges or "atolls," according to the nature of the sea-bottom and the depth (from 20 to 60 fathoms) they inhabit.

CORNBRASH.—A coarse shelly limestone of the upper oolite, said to derive its name from the facility with which it disintegrates and breaks up (*brashy*) for the purposes of corn-land.

COSMICAL (Gr. *kosmos*, the world).—Relating to the world or universe.

COSMOGONY (Gr. *kosmos*, world, and *gonè*, origin).—Reasoning or speculation as to the origin or creation of the universe.

COSMOGRAPHY (Gr. *kosmos*, world, and *grapho*, I write).—The science which treats of the several parts of the world, their laws and relations.

COSMOLOGY (Gr. *kosmos*, world, and *logos*, reasoning). — The science that treats of the laws which govern the physical universe: the study of the world in general.

CRAG (Celt. *creggan*, shell). — A shelly tertiary deposit of the pliocene epoch, occurring in Norfolk and Suffolk, and consisting of three members—the Mammaliferous, the Red, and the Coralline Crags.

CRAG AND TAIL (properly "Craig and Tail").—Applied to a form of secondary hills common in Britain, where a bold precipitous front is exposed to the west or north-west, and a sloping declivity towards the east.

CRANIA (Gr. *kranos*, a helmet or head-piece).—A genus of small brachiopodous molluscs, which attach themselves to other bodies, and consequently have the lower valve flat, and the upper limpet-like or helmet-shaped. They occur from the lower silurian to the chalk inclusive.

CRATER (Gr. *krater*, a cup or bowl).—The mouth or orifice of a volcano; so called from its cup or bowl-like shape. The craters of volcanoes have in general one side a little lower, owing to the prevailing winds carrying the greater portion of the light material (scoriæ and ashes) to the opposite side.

CRINOIDEA (Gr. *krinon*, lily, and *eidos*, form).—Literally lily-shaped; applied to a class of fossil echinoderms, having lily-like bodies supported on jointed calcareous stalks.

CRIOCERAS, CRIOCERATITE (Gr. *krios*, a ram, and *keras*, horn).—A genus of the ammonite family, peculiar to the lower chalk or greensand, and so named from its shape, the whorls being separate like the coils of a ram's horn.—See fig.

CROP.—The edge of any inclined stratum when it comes to the surface is called the crop or outcrop.

CRYSTAL (Gr. *krystallos*, ice).—Originally applied to transparent gems, but now extended to all minerals having regular geometrical forms. *Crystallised*, having the structure of a crystal; *crystalline*, confusedly crystallised; and *sub-crystalline*, indistinctly or faintly crystalline.

CTENOID, CTENOIDEAN (Gr. *kteis*, a comb, and *eidos*, form).—The third order of fishes in Agassiz's arrangement. They are distinguished by their scales, which are jagged or pectinated (like the teeth of a comb) on the posterior margin. The ctenoids appear with the chalk epoch; the perch is an example.

CTENOPTYCHIUS (*kteis*, *ktenos*, a comb, and *ptychè*, a wrinkle). — A genus of palatal teeth belonging to the cestraciont family, and found chiefly in the carboniferous limestone. They are readily distinguished by the serrated or comb-like margin of their free cutting edges.—See fig., Carboniferous System.

CULM (Welsh). — An inferior stony or shaly anthracite which burns with

little flame, and emits a disagreeable odour.

CUPRESSINITES (*cupressus*, the cypress-tree).—A genus of fossil fruits, evidently allied to the cypress order.

CUPRIFEROUS (Lat. *cuprum*, copper, and *fero*, I yield).—Yielding or containing copper.

CYCADITES.—Fossil plants of the younger secondary epochs, allied to the cycas and zamia.—See fig., Oolitic System.

CYCLOID, CYCLOIDEAN (Gr. *kyclos*, a circle, and *eidos*, form).—The fourth order of fishes in Agassiz's arrangement. They are distinguished by their scales, which are rounded, smooth, and simple at the margin. The cycloids are chiefly tertiary and recent species: the salmon and herring are examples.

CYCLOPTERIS (*kyclos*, a circle, and *pteris*, a fern).—An extensive genus of fern-like plants, ranging from the devonian to the oolite inclusive; and so called from the rounded or circular shape of their leaflets, which are entire, have no midrib, but are thickly marked with dichotomous veins, that radiate from the base to the margin.—See fig., Oolitic System.

CYPRIS.—A family of minute crustaceans having two flattish crusts or valves like those of a bivalve shell, and inhabiting the waters of lakes, marshes, and estuaries. Fossil species occur in all rocks, from the lower coal-measures upwards.—See figs., Carboniferous and Oolitic Systems.

CYSTIDEÆ (Gr. *kystis*, a bladder). — A family of silurian echinoderms, so called from their bladder-like shape. They appear to have been sessile, and not free moving, like the cidaris and sea-urchin.

CYSTIPHYLLUM (Gr. *kystis*, a bladder, and *phyllum*, leaf).—A genus of silurian corals, externally striated, and internally composed of small bladder-shaped cells.

D

DEBACLE. — A French term originally signifying the breaking up of the ice on a river—a freshet; but now applied to any sudden flood or rush of water which breaks down opposing barriers, and hurls forward and disperses blocks of stone and other debris.

DEBRIS (Fr., wreck or waste).—A convenient term, adopted from the French, for any accumulation of loose material arising from the waste of rocks: also for drifted accumulations of vegetable or animal matter.

DEGRADATION (Lat. *de*, down, and *gradus*, step).—Removing or wasting down step by step. The degradation of hills and cliffs is caused by atmospheric and aqueous agency; hence water is said to exert a *degrading* influence on the earth's crust.

DEINORNIS, DINORNIS (Gr. *deinos*, terrible, and *ornis*, bird).—A gigantic cursorial bird, whose remains have been discovered in a sub-fossil state in the river-silts of New Zealand.

DEINOSAURIA (Gr. *deinos*, terrible, and *sauros*, lizard).—The huge terrestrial saurians of the oolite and wealden have been so termed by Professor Owen. The order embraces the *iguanodon*, *megalosaurus*, and *hylæosaurus*.

DEINOTHERIUM (Gr. *deinos*, terrible, and *therion*, wild beast).—A huge proboscidean pachyderm found in the miocene tertiaries of France and Germany. Its zoological position is not yet distinctly ascertained.

DELTA.—The alluvial land formed at the mouth of a river, such as that of the Nile, which received this name from the resemblance of the space enclosed by the two main branches of the river to the Greek letter Δ, *delta*.

DENDRERPETON (Gr. *dendron*, a tree, and *erpeton*, a lizard).—A small lizard-like reptile from the coal-measures of Nova Scotia; so named from its being found in the hollow of a fossil trunk, and hence supposed to have been of arboreal habits.

DENDRITIC (Gr. *dendron*, a tree).—Applied to certain branching moss-like appearances, which occur on the surfaces of the fissures and joints in rocks. They are apt to be mistaken for fossil vegetation, but are strictly inorganic and of chemical origin.

DENUDATION (Lat. *de*, down, and *nudus*, naked).—Laying bare by removal. The removal of superficial matter, so as to lay bare the inferior strata, is an act of denudation; so also the removal by water of any formation or part of a formation.

DEPOSIT (Lat. *de*, down, and *positus*, placed).—Applied to matter which has settled down from suspension in water. Mud, sand, &c., are deposits, and are usually distinguished by the positions in which they occur, or by the agencies concerned in their formation, as fluviatile, lacustrine, marine, &c.

DERBY-SPAR.—A familiar name for fluate of lime or fluor-spar, from its occurring abundantly in the Derbyshire limestones. *See* Fluor-spar.

DETRITUS (Lat. *de*, down, and *tritus*, rubbed or worn).—An appropriate term for accumulations arising from the waste of exposed rock-surfaces.

DEVONIAN.—A synonyme of the old red sandstone, which is typically developed in Devonshire.

DIALLAGE (Gr. *diallagè*, interchange).—A siliceo-magnesian mineral, having a laminated or bladed cleavage, and so called from its changeable colour. Forms diallage rock, and enters into the composition of serpentine. Same as Schiller-spar, which see.

DIAMOND (Gr. *adamas*, unsubdued).—The diamond; so called in allusion to its hardness. The diamond is the most precious of known gems; and, chemically speaking, is crystallised carbon.

DICHOBUNE (Gr. *dicha*, divided in two, and *bounos*, a ridge).—A genus of anoplotheroid quadrupeds, whose remains occur chiefly in the eocene or lower tertiaries of Europe; and so called from the deeply-cleft ridges of the upper molars.

DICOTYLEDONOUS (Gr. *dis*, double, and *kotyledon*, seed-lobe).—A grand division of the vegetable kingdom, comprising all those plants whose seeds are composed of two lobes or seed-leaves. They are exogenous, or increase by external layers of growth, and the venation of their leaves is reticulated or net-like, and not in parallel order, as in monocotyledonous endogens.

DICTYOPHYLLUM (Gr. *diktyon*, a net, and *phyllum*, a leaf).—Literally "net-leaf," a provisional genus erected for the reception of all unknown fossil dicotyledonous leaves which exhibit the common reticulated structure. *Dictyophylla* have been found as low as the trias and permian.

DICYNODON (Gr. *di*, two, *kyon*, dog, and *odous*, tooth).—Literally "two-canine-teeth," a genus of very peculiar reptiles, occurring in sandstone, supposed to be of triassic age, in Southern Africa and Bengal. The principal remains yet found are the bones of the head, which seem to indicate a gigantic type between the lizards and turtles. The eye orbits are very large; the cranium flat, with nostrils divided as in lizards; and the jaws toothless, with the exception that the upper jaw possesses a pair of long tusks, implanted in sockets, and turned downwards like those of the walrus; hence the name *dicynodon*.—See fig., Triassic System.

DILUVIUM, DILUVIAL (Lat. *dis*, asunder, and *luere*, to wash).—Alluvium (which see) has been described as the term usually applied to matter brought together by the *ordinary* operations of water; diluvium, on the other hand, is regarded as implying the *extraordinary* action of water. In this sense it was at one time restricted to those accumulations of gravel, &c., supposed to have been the consequence of the Noachian deluge; but it has now a wider signification in Geology, being applied to all masses apparently the result of powerful aqueous agency.

DIP.—The inclination or angle at which strata slope from the plane of the horizon, or level.

DIPROTODON (Gr. *dis*, two, *protos*, first, and *odous*, tooth).—A gigantic pachydermoid marsupial mammal from the pleistocene or upper tertiary beds of Australia; and so termed from the large scalpriform character of its incisors or front teeth. The head of a specimen now in the British Museum measures three feet in length, and gives some idea of the immense size of the creature, which, while nearly related to the kangaroo, has, according to Owen, "osculant relationship with the herbivorous wombats."—See fig., Tertiary System.

DISINTEGRATION (Lat. *dis*, asunder, and *integer*, whole).—The breaking asunder of any whole or solid matter. The disintegration of rocks is caused chiefly by the slow action of frosts, rains, and other atmospheric influences.

DITHYROCARIS (Gr. *dithyros*, having two valves, and *karis*, shrimp).—A genus of phyllopod crustaceans first discovered by Dr Scoular in the coal shales of Lanarkshire, and so named from its being enclosed, like the existing genus *apus*, in a thin flattish bivalved carapace.—See fig., Carboniferous System.

DOLERITE (Gr. *doleros*, deceptive).—A variety of greenstone, composed of felspar and augite; so called from the difficulty of discriminating these compounds.

DOLOMITE (after M. Dolomieu).—A term for crystalline magnesian limestone, as distinguished from the earthy varieties.

DOMITE.—A granular, arenaceous-looking variety of trachyte found in the Puy de Dome, Auvergne; hence the name.

DROMATHERIUM (Gr. *dromaios*, swift-running, and *therion*, beast).—The name given to a small mammal, teeth, jaws, and detached bones of which have been discovered by Mr Emmons in the red sandstones of Virginia and N. Carolina—strata which, by some, are regarded as triassic, and by others as the equivalents of our European permians. Supposed to be like *amphitherium* and *phascolotherium* of marsupial affinity.—See fig., Triassic System.

DUNE (Brit., a hill).—Usually applied to hillocks of blown sand. *Sand-dunes*, sand-drift.

DYKE (Scot., a wall or fence).—Applied to those wall-like intrusions of igneous rock which fill up veins and fissures in the stratified systems. In general, they burst through and displace the strata, though occasionally they merely fill up rents and fissures.

E

ECHINITE (Gr. *echinos*, urchin).—A term for any fossil echinoderm.

ECHINODERMATA (Gr. *echinos*, urchin, and *derma*, skin).—A numerous class, recent and fossil, of radiata, like the star-fish and sea-urchin—all less or more covered with a firm coriaceous or crustaceous integument.

EDENTATA (Lat. *edentata*, toothless).—In Cuvier's arrangement, those mammals destitute of fore or incisive teeth. The order comprehends the *Edentata* proper—viz., ant-eaters, armadillos, &c.; the *Tardigrada* or sloths; and the *Monotremata*, which embraces the echnida and ornithorynchus.

EFFLORESCENCE (Lat. *effloresco*, I put forth flowers).—Applied in mineralogy to those saline excrescences which cover certain minerals, like alum shale, sulphuret of iron, &c., when exposed to the action of the atmosphere.

ELATERITE.—Elastic mineral pitch or caoutchouc. Masses of bitumen possessing a certain degree of elasticity are often found in the crevices of carboniferous limestones. On long exposure to the air elaterite becomes hard and brittle, like asphalt.

ELVAN, ELVAN COURSES.—A Cornish name for a felspathic rock, occurring in dykes, in the mining districts.

EMBOUCHURE (Fr.)—The mouth of a river; that part of a river where it enters the sea.

ENALIOSAURIA (Gr. *enalios*, marine, *sauros*, lizard).—Literally sea-saurians; a fossil group of reptiles, including the aquatic forms—ichthyosaurus, plesiosaurus, &c.

ENCRINITES (Gr. *krinon*, a lily).—An extensive class of fossil radiata, having a long jointed stalk, surmounted by a lily-shaped branching body. The internal calcareous skeletons of the encrinites are so abundant in some carboniferous limestones as to compose the greater portion of the mass; hence the term *encrinal* or *encrinital limestone*.

ENDOGENS (Gr. *endon*, within, *ginomai*, I am formed).—That division of the vegetable kingdom whose growth takes place from within, and not by external concentric layers, as in the *exogens*. *See* Monocotyledonous.

ENDOGENITES.—Fossil stems exhibiting the endogenous structure are so termed.

ENTOMOSTRACA (Gr. *entomon*, insect, and *ostrakon*, shell).—Literally shelled insect (from being provided with a broad shield or bivalved carapace); an extensive division of crustacea, so termed as contrasted with the soft-bodied malacostraca.

ENTROCHI (Lat. *trochus*, a wheel).—A name given to the wheel-like joints of the encrinite, which are frequently scattered through certain limestones; hence *entrochal marble*. *See* St Cuthbert's Beads.

EOCENE (Gr. *ēos*, dawn, and *kainos*, recent).—Sir C. Lyell's term for the lowest group of the tertiary system in which the dawn of recent life appears. The percentage of recent shells in the group is from 3 to 6; in the Miocene from 18 to 24; and in the Pliocene from 35 to 60.

EOLIAN (*Eolus*, god of the winds.)—A term occasionally employed to designate loose material (like sand) drifted and arranged by the wind. Thus we may have *Eolian* or *sub-aerial* accumulations as well as *aqueous* or *sedimentary*.

EQUISETITES (Lat. *equisetum*, the plant horsetail).—Fossil plants resembling the equisetum of our pools and marshes.

EREMACAUSIS (Gr. *eremè*, slow, solitary, and *kausis*, burning).—Liebig's term for slow chemical change; decay.

EROSION (Lat. *erosus*, gnawed or worn away).—The act of gradually wearing away; the state of being gradually worn away; as, for example, "valleys of erosion," or those valleys which have been gradually cut out of the solid strata by the long-continued action of the river or rivers that flow through them.

ERRATIC BLOCK GROUP.—A synonyme of the boulder clay, so called from the large transported blocks which are thickly strewn through it.

ESCARPMENT (Fr. *escarper*, to cut steep).—The abrupt face or cliff of a ridge or hill-range.

ESTUARY (Lat. *æstus*—*æstuo*, to boil—the tide; so called from the troubled boiling-up of the water-line which marks its approach).—Estuaries are, properly speaking, tidal river-mouths, like those of the Thames, Severn, Solway, &c., whose fauna and flora are mixed fresh-water and marine.

EUOMPHALUS (Gr. *eu*, well, and *omphalos*, the navel).—A coiled nautiloid shell of the mountain limestone—the coils not being in the same plane, like the ammonite; hence its umbilical shape.—See fig.

EURYPTERUS, EURYPTERIDÆ (Gr. *euros*, breadth, and *pteron*, wing or fin).—A genus and family of extinct crustaceans, ranging from the upper silurians to the lower coal-measures in-

clusive, and so termed in allusion to their broad oar-like swimming feet. The family embraces *eurypterus* proper, *pterygotus*, and others, all characterised by their long lobster-like bodies of eleven segments, their more or less pointed tail-plate, and broad cephalic carapace, on the under side of which are situated the foot-jaws or organs of mastication, as in the existing king-crab.—See fig., Silurian System

EXOGENS (Gr. *exo*, without, and *ginomai*, I am formed).—That division of the vegetable kingdom whose growth takes place by external concentric layers. *See* Dicotyledonous.

EXOGENITES.—Any fragment of fossil wood exhibiting the exogenous structure, and otherwise of unknown affinity, is so termed.

EXUVIÆ (Lat., cast clothes).—In Zoology this term is applied to the moulted or cast-off coverings of animals, such as the skin of the snake, the crust of the crab, &c.; but in Geology it has a somewhat wider sense, and applies to all fossil animal matter of whatever description.

F

FACET (Fr. *facette*, a little face).—Applied to the small terminal faces of crystals and cut gems.

FACIES (Lat.)—A convenient term recently introduced to express any common resemblance or aspect among strata, fossils, minerals, and the like.

FAIKES or FAKES.—A Scotch miner's term for fissile, sandy shales, or shaly sandstones, as distinct from the dark bituminous shales known as "blaes" or "blaize."

FALCIFORM (Lat. *falx*, a reaping-hook, and *forma*).—Shaped like a scythe or reaping-hook.

FALUNS.—A French provincial term for the shelly tertiary strata of Touraine, which resemble the "crag" of Norfolk and Suffolk.

FAULT.—The term for any fissure accompanied by a displacement of the strata on either side. On one side the strata may be thrown down many fathoms, on the other thrown up; and, at the same time, may be altered in their dip or inclination.

FAUNA (rural deities).—A convenient term for the animals of any given epoch or area.

FAVOSITES (Lat. *favus*, a honeycomb).—A genus of silurian sessile-spreading corals.

FAVULARIA (Lat. *favosus*, honeycombed).—A genus of coal-measure plants, having furrowed stems, and square-shaped leaf scars on the ridges. The favularia, like the lepidodendron, seems to have been clothed with densely imbricated leaflets.—See fig., Carboniferous System.

FELSPAR (Ger., rock-spar).—An abundant mineral, composed of silica and alumina with soda or potash, and variously coloured, which enters largely into the composition of all igneous rocks—granite, porphyry, greenstone, and trachyte.

FELSPATHIC.—Composed of, or abounding in, felspar; applied to certain traps, porphyries, claystones, &c.

FENESTELLA (Lat., a little window).—An extensive genus of polyzoans, resembling the *retepora* and *flustra* of existing shores, and found in all the palæozoic strata from the silurian upwards.

FERRUGINOUS (Lat. *ferrum*, iron).—Impregnated with oxide of iron. *Ferriferous*, yielding iron.

FILICOID (Lat. *filix*, fern, and *eidos*, likeness).—Applied to plants, recent or fossil, which resemble or partake of the nature of the fern tribe.

FIRECLAY.—Any clay capable of resisting a great heat without slagging or vitrifying. This property arises from the absence of any alkaline earth to act as a flux. Fireclays abound in the coal-measures.

FIRE-DAMP.—A miner's term for light-carburetted hydrogen, which, when diffused in the atmosphere of the coal-workings to the amount of one-thirteenth by volume, becomes explosive. *See* Choke-damp.

FIRESTONE.—Any stone that stands heat without injury; generally applied to certain cretaceous and oolitic sandstones employed in the construction of glass furnaces. In geological classification a calcareo-arenaceous member of the upper greensand as developed in Surrey.

FLABELLARIA (Lat. *flabellum*, a fan).—A provisional genus intended to embrace all those broad, flabelliform, palm-like leaves, which occur particularly in the coal formation and tertiary lignites.

FLAGSTONE.—A quarryman's term for any fissile sandstone like the Arbroath paving-stone.

FLINT (Sax.), or siliceous earth, as it occurs in nodules in the chalk, contains about 98 per cent of silex, with traces of lime, iron, and water.

FLORA (the goddess of flowers).—A convenient term for the vegetation of any given epoch or area.

FLÖTZ (Ger.)—A term applyed by Werner to the secondary strata, because they

were flötz, or flat-lying, compared with the primary and transition rocks.

FLUOR-SPAR (Lat.)—Fluate of lime, or fluoride of calcium, consisting of 67.75 lime and 32.25 fluoric acid. It occurs either in crystals, foliated, or earthy and massive.

FLUVIATILE (Lat. *fluvius*, a river).—Belonging to a river, or produced by river action.

FLYSCH.—A provincial Swiss term for a series of tertiary strata consisting of dark-coloured slates, marls, and fucoidal sandstones immediately overlying the nummulitic limestone.

FORALITES (Lat. *foro*, I bore).—Applied to certain tube-like markings which occur in sandstones and other strata, and which seem to have been the burrows of *annelids* having the habits of the common lob-worm.

FORAMINIFERA (Lat. *foramen*, a passage).—The name given by D'Orbigny to a group of minute, many-celled organisms, the calcareous cells of which are pierced like a sieve with numerous pores or *foramina* for the protrusion of the delicate filaments of the protozoa that inhabits them. They are microscopic organisms (*Protozoa*), and abound in all formations, as well as in the sediments of existing seas.

FORMATION.—This term is often loosely used by geologists, but should be restricted to any assemblage of rocks connected by geological position, by immediate succession in point of time, and by organic and mineral affinities.

FOSSIL (Lat. *fossus*, dug up).—Technically applied in Geology to all petrified remains of plants and animals found in the earth's crust. When only partially petrified, or recent, the term *subfossil* is employed.

FOSSILIFEROUS.—Applied to strata containing organic remains.

FREESTONE.—Any rock which admits of being freely cut and dressed by the builder; generally applied in Scotland to sandstone.

FUCOID (*fucus*, sea-weed, and *eidos*, form).—Fucoids, or fucus-like impressions, occur on strata of every age, from the lower silurians to the upper tertiaries.

FULLER'S EARTH.—A term applied to certain soft unctuous clays of the oolite and chalk systems, from their being employed in the fulling of woollens. Any fine clay, containing from 20 to 30 per cent of alumina, will act as a grease-absorbent or fuller's clay.

FUMEROLE (Ital. *fumare*, to smoke).—An opening or orifice in a volcanic district, from which eruptions of smoke and other gaseous fumes are emitted.

G

GALENA (Gr. *galeo*, I shine).—Sulphuret of lead; lead-glance—so called from its lustre.

GALERITES (Lat. *galea*, a helmet).—A helmet-shaped sea-urchin of the chalk period.

GANNISTER.—The local name of a fine hard-grained grit which occurs under certain coal-beds in Derbyshire, Yorkshire, and north of England.

GANOID, GANOIDEAN (Gr. *ganos*, splendour).—The second order of fishes in Agassiz's arrangement, having angular scales regularly arranged, and covered with a strong shining enamel. The ganoids are chiefly palæozoic and extinct forms: the bony pike of Canada and the sturgeon are living examples.

GASTEROPODA (Gr. *gaster*, belly, and *pous*, foot).—A class of mollusca which, like the periwinkle and garden snail, have a distinct head, and move by means of a muscular foot attached to the lower part of the body.

GAULT.—A provincial term for the chalky clays which occur in the lower division of the chalk system.

GEODES (Gr. *geodes*, earthy).—Originally applied to nodules of indurated clay or ironstone hollow within, or filled with soft earthy ochre; but now generally to all rounded nodules having internal cavities, whether empty or lined with crystals.

GEOGNOSY (Gr. *gè*, the earth, and *gnosis*, knowledge).—A term invented to express absolute knowledge of the earth, in contradistinction to *geology*, which embraces both the facts and our reasonings respecting them.

GEOLOGY (Gr. *ge*, the earth, and *logos*, doctrine).—Embraces all that can be known of the constitution and history of our planet.

GEOSAURUS (Gr. *gè*, the earth, and *saurus*, lizard).—A gigantic terrestrial reptile of the oolitic epoch.

GERVILLIA (dedicated to M. Gerville, a French naturalist).—A genus of the Aviculidæ, or wing-shells, found fossil in many species, from the carboniferous system to the chalk inclusive.

GEYSER.—Literally "rager;" an Icelandic term for the intermittent boiling springs, or spouting fountains, which occur in connection with the volcanic phenomena of that island.

GLACIER (Lat. *glacies*, ice).—Applied to those masses of ice, or of snow and ice, which collect in the valleys and ravines of snowy mountains like the Alps, and which move downward with a peculiar motion, smoothing the rocks over which

they pass, and leaving mounds of debris (*moraines*) as they melt away.

GLANCE.—A frequent term of the earlier mineralogists — as lead-glance, iron-glance, glance-coal, &c.; it is now little used.

GLANCE-COAL. — Another name for anthracite, in allusion to its semi-metallic lustre.

GLOSSOPTERIS (Gr. *glossè*, the tongue, and *pteris*, fern.—A genus of oolitic ferns, so called from their tongue-shaped leaves (which are four-parted), and now known as *Sagenopteris*.—See fig.

GLYPTODON (Gr. *glyptos*, sculptured, and *odous*, tooth). — So named from the deeply-grooved teeth; a gigantic edentate animal from the upper tertiaries of South America; allied to the armadilloes (*Dasypinæ*), and furnished with a carapace or coat of mail, formed of polygonal bony plates, united by sutures, which constituted an impenetrable covering for the upper part of the body.—See fig., Tertiary System.

GNEISS.—A German miner's term for the granitoid schists of the oldest or primary strata.

GONIATITE (Gr. *gonia*, an angle). — A genus of the ammonite family, ranging from the devonian to the trias, and so called from the angular lines which mark the junctions, or sutures, of its chambers.—See fig.

GRANITE.—Literally grain-stone; an aggregate of felspar, quartz, and mica. *Granitic*, belonging to the granite series; *granitoid*, having the aspect of granite.

GRAPHITE (Gr. *grapho*, I write). — So called from its use in making writing-pencils. This substance consists almost entirely of pure carbon with a small percentage of iron, the proportions being about 90 to 9. It is also termed *plumbago* and *black-lead*, from its appearance, though lead does not at all enter into its composition.

GRAPTOLITES (Gr. *graptos*, written, and *lithos*, stone).—Characteristic silurian zoophytes, apparently akin to the virgularia or sea-pen of modern seas; hence the name.

GREEN-EARTH.—A soft variety of chlorite or talc, of a greenish or blackish-green colour, often found coating the cavities of amygdaloid, and occurring as the colouring matter of the "greensand."

GREENSAND. — The lower members or group of the chalk system; so called from many of the beds being coloured green with chlorite or green-earth.

GREENSTONE.—A prevalent igneous rock composed of felspar and hornblende.

GREYSTONE.—A variety of trachyte, composed of felspar and augite; allied to dolerite.

GREYWACKE (Ger. *Grauwackè*).—A German term originally employed to designate the argillo-arenaceous beds of the transition rocks, and subsequently as a name for the entire transition series. It is now seldom used.

GRIT.—Any hard sandstone in which the grains of quartz are less-rounded or "sharper" than in ordinary sandstones is technically termed a *grit*—as mill-stone-grit, grindstone-grit.

GRYPHÆA, GRYPHITE (Lat. *gryps*, a griffin).—A beak-shaped inequivalved shell of the oyster family, and abounding in the oolite and upper secondaries.—See figs., Oolitic System.

GYMNODONTS (Gr. *gymnos*, naked, and *odous*, tooth).—A family of fishes belonging to the order *Plectognathi* (soldered jaws), and including the globe-fish, trunk-fish, &c., in which the jaws are covered with a substance resembling ivory arranged in small plates, representing united teeth. The *gymnodonts* appear only in the chalk and tertiary formations.

GYMNOSPERMS (Gr. *gymnos*, naked, and *sperma*, seed).—Flowering plants with naked seeds, and wood in concentric layers like the pine tribe. Same as *Gymnogens*.

GYPSUM.—Sulphate of lime, plaster-of-Paris, or stucco-stone. The Greek word *gypsos* signifies lime in general; and seems to be derived from *gè*, earth, and *epso*, I boil, in allusion to the heat given off when burnt lime is slaked with water.

GYRACANTHUS (Gr. *gyros*, a circle or spire, and *akantha*, a spine). — Literally "spiral or twisted spine;" a genus of cestraciont fin-spines or ichthyodorulites occurring in the carboniferous and permian formations, often from ten to eighteen inches in length, and so termed from the sculptured ridges with which they are ornamented, and which run in a spiral or twisted-like manner, from the base upwards.—See fig.

GYROGONITES (Gr. *gyros*, twisted, and *gonos*, seed). — The spiral seed-vessels of plants allied to the chara, and found in fresh-water tertiaries.

H

HABITAT. — Applied in botany to the country or district in which a plant grows wild; the tract or range to which it seems limited by external conditions of soil, climate, &c.

HÆMATITE (Gr. *haima*, blood). — Red

oxide of iron; an abundant ore found in veins and masses.

HAMITE (Lat. *hamus*, a hook).—A genus of hook-shaped chambered shells peculiar to the chalk and greensand.

HEAVY-SPAR.—Sulphate of barytes; also known as baro-selenite, and prismatic heavy-spar.

HELIOLITES (Gr. *helios*, the sun, and *lithos*, stone.—An extensive genus of silurian and devonian corals; so called from the central-radiating or sun-like aspect of its pores compared with those of the *astræa* or star-corals.—See fig.

HIPPOTHERIUM (Gr. *hippos*, horse, and *therion*, wild beast).—A mammal of the miocene tertiaries, apparently allied to the horse family.

HIPPURITE (Gr. *hippos*, a horse).—A massive horse-hoof-like bivalve of the chalk, having a deep conical under-valve, with a flat lid or upper valve. —See fig., Cretaceous System.

HIPPURITES.—A genus of coal-measure plants, so called from their resemblance to the common *hippuris vulgaris* or mare's-tail of our marshes. If they grew in the same relative proportions as the existing hippuris, many of the fragments found would indicate a height of from 15 ft. to 20 ft.—See fig., Carboniferous System.

HOLOPTYCHIUS (Gr. *holos*, entire, and *ptychè*, wrinkle).—All-wrinkle: a fish of the devonian and carboniferous epochs, so called from the wrinkle-like surface of its scales.—See fig., Devonian System.

HOMOLOGY (Gr. *homos*, the same, and *logos*, reasoning).—In general terms, the idea or doctrine of the answerable relation of parts in animal structures: *e.g.*, the bones of the human arm and hand find their homologues or answerable parts in the wing of the bird, in the fore-limb of the quadruped, and in the paddle of the whale.

HORNBLENDE.—A mineral of frequent occurrence in granitic and trappean rocks; so called from its horn-like cleavage and peculiar lustre (*blenden*, to dazzle). It is usually of a black or dark-green colour, softer than quartz or felspar, but heavier than either, and emits a peculiar bitter odour when breathed on. It generally occurs confusedly crystalline, forming with quartz "hornblende rock," with quartz and felspar "syenite," and with felspar alone the numerous varieties of "greenstone."

HORNITOS or HORNOS.—Literally ovens; a Spanish term for the low oven-shaped mounds or hillocks so frequent in the volcanic districts of South America, and from whose sides and summits columns of hot smoke and vapours are usually emitted.

HORNSTONE.—A mixed siliceous mineral and rock of various colours, having a dull splintery or sub-conchoidal fracture, and very much the aspect of a tough massive flint. It is sometimes difficult to distinguish between jasper, flint, chert, and hornstone, though the latter term is more appropriately applied to all compact, tough, and massive varieties of siliceous rock. It consists chiefly of silex and alumina, and differs from the felspars in containing no soda or potash; hence its infusibility. A common igneous rock, consisting of hornstone, with imbedded crystals of quartz or felspar, is known as *hornstone porphyry*.

HYBODONTS (Gr. *hybos*, humped, and *odous*, tooth).—A family of fossil shark-like fishes with peculiar knob-like teeth.

HYDRO-CARBONS, HYDRO-CARBURETS.—Composed of hydrogen and carbon: a term usually applied to the bitumens, mineral resins, and mineral fats, which are chiefly or altogether composed of hydrogen and carbon in varying proportions; *e. g.*, naphtha, petroleum, asphalt, amber, ozokerite, &c.

HYLÆOSAURUS (Gr. *hyla*, a wood, *weald*, or forest, and *saurus*, a lizard).—One of the dinosaurs; a gigantic terrestrial reptile, whose remains were first discovered (1832) by Dr Mantell in the wealden strata of Tilgate forest; hence the name.

HYMENOCARIS (Gr. *hymen*, membrane, and *karis*, shrimp).—A small phyllopod or shrimp-like crustacean of the silurian epoch, having its anterior portion enclosed in a thin bivalvular carapace, and its abdominal or terminal segments free and capable of being turned under the body.

HYPOGENE (Gr. *hypo*, under, and *ginomai*, I am formed.—A term employed by Sir Charles Lyell as a substitute for *primary*, merely to mark the formation or transformation of these strata from below, without involving any theory as to their age.

HYPOZOIC (Gr. *hypo*, under, and *zoè*, life). —Applied to those rocks which, like gneiss and mica-schist, lie beneath the fossiliferous strata, and which have yet yielded no organic remains. "Azoic" means destitute of fossils; "hypozoic" simply points out their position, without offering any opinion as to their fossiliferous or non-fossiliferous character.

I

ICEBERG (Ger. *eis*, ice, and *berg*, mountain).—The name given to the mountainous masses of ice often found floating in the polar seas. Sometimes they

are formed by the accumulation of ice and snow; at other times they seem to have been originally glaciers launched from precipitous coasts into the ocean, and there further augmented by numbers of them freezing *en masse*. Icebergs have been seen in the arctic and antarctic oceans several miles in circumference, rising from 40 to 200 feet above the water, and loaded with blocks of rock and masses of shingle. Some idea of their size may be formed from the fact that little more than an eighth of their bulk rises above the surface. As they are floated by the polar currents to warmer latitudes they melt away, dropping their burdens of boulder and rock debris on the bottom of the ocean.

ICE-FLOE (Dan., ice-island).—Applied by voyagers to the smaller masses of ice that encumber the polar seas.

ICHNITES (Gr. *ichnon*, a footprint).—A term applied to all fossil footprints, many of which have been discovered in secondary formations—as *ornithichnites*, bird-footsteps, *sauroidichnites*, saurian footsteps, &c.—See figs.

ICHNOLOGY, or ICHNOLITHOLOGY (Gr. *ichnon*, a footprint, *lithos*, stone, and *logos*).—The science of fossil footprints; *e. g.*, the "Ichnology of Annandale," by Sir William Jardine.

ICHTHYODORULITE (Gr. *ichthys*, fish, *doru*, spear, and *lithos*, stone).—The fossil fin-spines or defences of fishes found abundantly in all the fossiliferous strata.

ICHTHYOLITE (Gr. *ichthys*, fish, and *lithos*, stone).—A palæontological term for a fossil fish, or any portion of a fish, as a scale, tooth, spine, &c. The most celebrated deposits of fossil fishes in Europe are the bituminous schists of the lower old red of Orkney and Caithness; the yellow sandstones (upper old red) of Dura Den, Fifeshire; the lower coal-measures of Burdiehouse, &c., near Edinburgh; the coal formation of Saarbrück in Lorraine; the permian bituminous slate of Mansfeld in Thuringia; the calcareous lithographic slate of Solenhofen (oolitic); the compact blue slaty shale of Glaris (cretaceous); and the tertiary limestones of Monte Bolca, near Verona, the marlstones of Oeningen in Switzerland, and of Aix in Provence.

ICHTHYOSAURUS (Gr. *ichthys*, a fish, and *saurus*, lizard).—A marine reptile of the oolitic epoch, having some analogies to fishes.—See fig.

IGNEOUS (Lat. *ignis*, fire).—Applied to all agencies, operations, or results which seem connected with or to have arisen from subterranean heat, as "igneous rocks," "igneous fusion," &c.

IGUANODON (*iguana*, and *odous*, tooth).—A colossal lizard-like reptile found in the wealden strata; so called from the resemblance of its teeth to those of the existing iguana.

INDURATED (Lat. *durus*, hard).—Restricted in Geology to rocks that have been hardened by the action of heat, and in this sense distinct from "hard" or "compact."

INFUSORIA.—Minute animal organisms or animalcules (fossil and recent); so called from their being readily obtained by infusing vegetable matter in water. They are found in all stagnant waters, and their exuviæ enter largely into the composition of many aqueous deposits.

INOCERAMUS (Gr. *is*, *inos*, fibre, and *keramos*, shell).—A genus of fossil bivalves belonging to the *aviculidæ* (wing-shells or pearl-oysters), and so named from the fibrous structure of their shells, which are unequal valved, ventricose, and radiately or concentrically furrowed.

IN SITU (Lat.), literally, in its natural position or place.—A rock or fossil is said to be "*in situ*," when it is found in the situation or place in which it was originally formed or deposited.

INTERCALATED, INTERCALATION.—Subordinate beds of a different nature occurring between the main beds of a series are said to be *intercalated*: the occurrence of such beds or of intervals of deposition are said to be *intercalations*.

INVERTEBRATA.—Animals without vertebræ or backbones, including the mollusca, articulata, and radiata.

IRONSTONE.—The usual term for the carbonates of iron found in nodules or thin layers in the shales of the secondary rocks. They are all more or less argillaceous—hence the term "clay carbonate." "Clay ironstone" is generally used, however, to distinguish the clay carbonates from the "black-bands," which are admixtures of coaly matter, clay, and carbonate of iron, found in the Scottish coal-fields.

J

JADE.—A hard, tough, siliceous rock, of a leek-green colour, smooth surface, and somewhat soapy feel. It is susceptible of a fine polish, as may be seen in the New Zealand axes, hangers, idols, &c., so common in our museums.

JASPER.—A somewhat loosely applied term to many siliceous compounds. When quartz is combined with a certain portion of alumina and iron it loses its translucency and becomes jasper.

JET (*gagites*, from Gaga, a river in Asia

Minor).—This well-known substance is rather a species of amber than coal. It occurs in nodules and lumps in lignitic strata; is electric when rubbed; is more resinous in lustre than the finest cannel-coal; and is also specifically lighter.

JOINTS.—The fissures or rents which divide certain strata into blocks more or less regular are properly so termed. This jointed structure seems in many cases to have arisen from shrinkage or contraction of the deposit while in the process of solidifying.

JUNCITES (Lat. *juncus*, a rush).—Fossil stems and leaves apparently related to the *juncaceæ* or rush family, which are chiefly inhabitants of marshy tracts in the temperate and colder regions. Such striated, grooved, and tapering rush-like fragments of leaves occur from the devonian formation upwards, but their true affinities are not yet determined.

JURASSIC.—A synonyme of the oolitic system, from the characteristic occurrence of its rocks in the Jura Mountains.

K

KAMPECARIS (Gr. *kampê*, a grub or caterpillar, and *karis*, shrimp).—A small 13-segmented crustacean, discovered by the author in the grey flagstones (lower old red) of Forfarshire, and so named from its appearance. From its imperfect preservation its real affinities cannot be well ascertained; that is, whether it be a small phyllopod, or the larval stage of some larger crustacean.

KAOLIN (Chinese).—The name given to the finest porcelain clay, arising from the decomposition of felspar in soft earthy granites.

KEIL.—The same as reddle (*rœthel*) or red clay. An argillaceous peroxide of iron, of a fine deep red, and used for marking.

KEUPER (Ger.)—Literally copper; an abbreviated term for the upper member of the trias, which consists in Germany of variegated cupriferous marls and marl-slates.

KILLAS.—A Cornish name for a coarse argillaceous schist, in which many of the metalliferous veins of that district occur.

KIM-COAL.—A provincial term for a highly bituminous shale occurring in the oolitic beds at Kimmeridge.

KNORRIA (after Knorr).—A genus of coal-measure plants, embracing those stems the leaves of which were densely arranged in spiral manner, and left *projecting* instead of depressed leaf scurs. They are usually ranked as lycopods, but seem intermediate between them and the coniferæ.—See fig.

KUNKER.—A Hindostanee term for an extensive superficial accumulation of light-brown or reddish concretionary earthy clay, which in point of time seems to correspond pretty well with the "drift" or "boulder clay" of Europe.

KUPFER-SCHIEFER (Ger.)—Literally copper-slate; a dark, bituminous-looking schist associated with the zechstein of Germany, and extensively worked as a copper ore.

L

LABRADORITE.—Called also Labrador felspar, from the locality where first found: a species of felspar having a peculiar pearly and irridescent play of colours when the light falls on it in certain directions.

LABYRINTHODON (Gr. *labyrinthos*, a place full of intricate passages, and *odous*, tooth).—A name given by Professor Owen to a batrachian reptile of the new red sandstone, in allusion to the labyrinthine structure exhibited by sections of its teeth.—See fig.

LACUSTRINE (Lat. *lacus*, a lake).—Of or belonging to a lake, as lacustrine deposits.

LAGOON or LAGUNE (Ital. *laguna*).—Generally applied, as in the Adriatic, to shallow salt-water lakes or sheets of water cut off (or nearly so) from the sea by intervening strips of beach or river-deposit; also to the waters enclosed by circular coral reefs; as well as to the lake-like sheets that frequently occur in tidal and periodically inundated deltas.

LAMINATED (Lat. *lamina*, a thin plate).—Applied to strata splitting up into thin layers, as certain flagstones and tilestones.

LAPIDIFY, LAPIDIFICATION (Lat. *lapis*, stone, and *fio*, I become).—Conversion into stone; the process by which soft, loose, or incohering substances (organic or inorganic) are converted into stony matter.

LAPILLI (*lapillus*, a little stone).—Applied to a peculiar variety of volcanic cinders, or slaggy concretions.

LATERITE (Lat. *later*, a brick).—Literally

"brick-stone;" a peculiar clayey deposit of middle tertiary age, found in India, and so named from being cut into bricks and used for building. Some portions of it, however, pass into a compact jaspideous rock, and other portions deteriorate into soft ochrey or gritty clays.

LAVA.—The general term for all rock matter which flows in a melted state from volcanoes.

LEPIDODENDRON (Gr. *lepis*, a scale, and *dendron*, tree).—An abundant family of fossil plants, so called from the scale-like arrangement of their leaf-scars. They are especially characteristic of the carboniferous epoch.—See fig.

LEPIDOPHYLLUM (Gr. *lepis*, scale, and *phyllon*, leaf).—Small lanceolate leaves occurring in the shales of the coal-measures, evidently of a woody rigid texture, having a midrib, and triangular at the base or point of attachment. They are regarded as the leaves of *Lepidodendron*.

LEPIDOSTROBUS (Gr. *lepis*, a scale, and *strobilos*, a fir-cone).—Fossil cone-like organisms occurring in the coal formation, and evidently the fruit or seed-cones of coniferous, lepidendroid, and other trees of that period.

LIAS.—This term is said to be a corruption of lyers or layers, and was originally applied to those thin-bedded limestones occurring at the base of the oolitic system. It is now extended to the group or system lying between the oolite and trias.

LIGNITE (Lat. *lignum*, wood).—Wood-coal, or fossil wood converted into a kind of coal. *See* Brown-Coal.

LITHOGRAPHIC SLATE or STONE.—Certain magnesian limestones used for the purposes of lithography (Gr. *lithos*, stone, and *grapho*, I write), are so termed.

LITHOLOGY, LITHOLOGICAL (Gr. *lithos*, a stone, and *logos*, doctrine).—Applied to the mineral characteristics or stratigraphical relations of rock-groups, in contradistinction to their *palæontology* or palæontological aspects.

LITTORAL (Lat. *littus*, the shore).—Applied to operations and deposits which take place near the shore, in contradistinction to those of a deep-water or *pelagic* character.

LITUITES (Lat. *lituus*, a trumpet), a genus of nautiloid chambered shells peculiar to silurian strata, and so named from their form—the inner whirls being partially coiled up, and the last chamber being produced into a straight, trumpet-like tube. See fig., Silurian System.

LLANOS (Span.)—In physical geography, the flat treeless plains that extend along the banks of the Orinoco. They are, for the most part, within the tropics, and during one-half of the year are covered with grass, and for the rest desolate.

LOAM.—Any soil composed of clay and sand, and which is neither distinctly sandy nor clayey, is called loam.

LODE.—A Cornish term for any regular vein or course, whether metalliferous or not.

LOESS or LEHM.—A German term for an ancient alluvial deposit of the Rhine replete with fresh-water shells of existing species. According to Lyell, "it is a finely comminuted sand or pulverulent loam of a yellowish-grey colour, consisting chiefly of argillaceous matter, combined with a sixth part of carbonate of lime and a sixth of quartzose and micaceous sand."

LOPHIODON (Gr. *lophos*, a crest or ridge, and *odous*, tooth).—An extinct tapir-like pachyderm of the tertiary epoch; so called from the eminences on its teeth.

LYCOPODITES.—Fossil plants apparently allied to the locopodiums.

LYDIAN-STONE.—Flinty slate or black jasper; a siliceous rock allied to burr-stone, but of a greyish-black colour.

M

MACHAIRODUS (Gr. *machaira*, a sabre, and *odous*, tooth).—A genus of carnivorous mammals found in the upper tertiaries and bone-caves of Europe; and so called from the trenchant sabre-shape of its upper canines. There were several species, some as large as the grizzly bear and lion, others about the size of the leopard and under. Professor Owen finds its nearest affinities in the lion; hence his synonyme of *felis spelæa*.

MADREPORITE.—Fossil madrepore; also a variety of limestone having a small prismatic structure which looks like the pore-arrangement of true coral.

MAGNESIAN LIMESTONE.—Any limestone containing upwards of 20 per cent of carbonate of magnesia may be so called. The term is also used as synonymous with Permian or Lower New Red Sandstone.

MALACHITE.—The green carbonate of copper, consisting of 71.8 copper protoxide, 20 carbonic acid, and 8.2 water, and deriving its name, it is said, from the Greek *malachè*, the marsh-mallow, in allusion to its colour.

MAMMILLARY (Lat. *mamilla*, little pap).—Applied to surfaces covered with pap-like concretions, as some magnesian limestones. *See* Botryoidal.

MAMMOTH (Tartar).—The fossil elephant (*elephas primigenius*) of Siberia and northern Europe—differing from the existing elephant chiefly in its greater size, the rougher ridges of its molars, its immense recurved tusks, and its dense covering of shaggy hair. See fig., Tertiary System.

MANTELLIA.—Considering the fossil cycadeoidea of the Isle of Portland as a peculiar type, M. Brongniart has referred them to a new genus, under the name of Mantellia, in honour of Dr Mantell. —See fig., Oolitic System.

MARBLE.—Any rock susceptible of a fine polish is termed "Marble" by the stone-cutters. The term, however, should be restricted to limestones.

MARL (Sax.)—Any soft admixture of clay and lime is termed a marl; "clay-marl" when the clay predominates; "marl-clay" when the lime is most abundant; and "shell-marl" when it contains fresh-water shells, as the lymnea, paludina, &c.

MARSUPIALIA, MARSUPIAL (Lat. *marsupium*, a pouch or purse).—Literally pouched animals; a marked division of the mammalia, having a sack or pouch under the belly, in which they carry their young, as the kangaroo and opossum. They are sometimes termed *ovoviviparous* mammals, as being intermediate between the viviparous mammals and the oviparous birds and reptiles. For the same reason they are classed as *implacental*, in contradistinction to the true *placental* mammals—the pouch-like apparatus for their imperfect young being a sort of extra-uterine gestation.

MARSUPITE (Lat. *marsupium*, a purse).—A genus of free-floating crinoidea found in the chalk, having a bag-like shape when closed; known by the quarrymen's term "cluster-stone." See fig., Chalk Formation.

MASTODON (Gr. *mastos*, nipple, and *odous*, tooth).—A genus of tertiary elephantine mammals, so called from the nipple-like protuberances on the grinding surfaces of the molar teeth.—See fig.

MATRIX (Lat., the womb).—The rock or main substance in which any accidental crystal, mineral, or fossil is imbedded, is called the *matrix* of that mineral or fossil.

MEGACEROS (Gr. *mega*, great, and *keras*, horn).—Literally "great antlered;" the fossil or sub-fossil gigantic deer of our pleistocene marls and peat-bogs, often, but erroneously, termed the "Irish elk."—See fig., Tertiary System.

MEGALICHTHYS (Gr. *megalè*, great, and *ichthys*, fish).—A large sauroid fish of the carboniferous epoch, characterised by its smooth, enamelled, lozenge-shaped scales, dotted by frequent small punctures. The teeth of *megalichthys* were numerous, sharp, and conical, and small in comparison with those of *rhizodus*, with which it is frequently confounded.

MEGALONYX (Gr. *megalè*, great, and *onyx*, claw).—A huge tertiary mammal of the edentate order, so called from the great size of its claw- or unguical-bones.

MEGALOSAURUS (Gr. *megalè*, great, and *saurus*, lizard).—A huge land-reptile of the oolitic period.

MEGATHERIUM (Gr. *mega*, great, and *therion*, beast).—A huge tertiary mammal found in South America, and allied to the sloth.—See fig., Tertiary System.

MESOZOIC (Gr. *mesos*, middle, and *zoè*, life).—The great division of stratified groups holding the middle forms of life, as differing from the Palæozoic and Cainozoic.

METAMORPHISM (Gr. *meta*, change, and *morphè*, form), literally transformation.—That change of structure or of texture which has been effected on many rocks by the agency of heat, chemical action, or otherwise.

MICA (Lat. *mico*, I shine).—A mineral well known from its metallic lustre and divisibility into thin shining flakes. It occurs crystallised in granite, the disintegration of which has supplied it to the subsequently-formed sedimentary rocks.

MICA-SCHIST (also called, but improperly, "Mica-slate").—A metamorphic foliated rock composed of mica and quartz.

MILIOLITE LIMESTONE.—A name given by French geologists to certain beds of the calcaire grossier round Paris, because entirely made up of millions of minute foraminiferous shells.

MILLSTONE GRIT.—A group of the English carboniferous system, so called from its hard gritty sandstones, which are used for millstones.

MIOCENE (*meion*, less, and *kainos*, recent).—Sir Charles Lyell's term for the middle tertiaries, as holding a less percentage of recent species than the pliocene. *See* Eocene.

MOLASSE (Lat. *mollis*, soft).—Certain soft arenaceous beds which compose the middle tertiaries of Switzerland.

MONOCOTYLEDONOUS (Gr. *monos*, one, and *kotyledon*, seed-lobe).—Plants whose fruit has only one seed-lobe, and consequently *endogenous* in growth, like palms, lilies, grasses, &c.

MORAINES.—The name given in Switzerland to the longitudinal mounds of stony detritus which occur at the bases and along the edges of all the great glaciers. The formation of these accumulations is thus explained by Professor Agassiz. The glaciers, it is well known, are continually moving downwards, in

consequence probably of the introduction of water into their fissures, which in freezing expands the ice; and the ice, being thus loosened or detached from the rocks below, is gradually pressed forward by its own weight. In consequence of this motion, the gravel and fragments of rocks which fall upon the glaciers from the sides of the adjacent mountains are accumulated in longitudinal ridges or *moraines* as the glacier melts away.

MOSÆSAURUS.—A gigantic marine reptile of the upper chalk, apparently allied to the monitor; and so called from its being found in the Mæstricht beds.

MOYA (Span.)—A term applied in South America to the fœtid sulphurous mud discharged by certain volcanoes.

MUSCHELKALK (Ger.)—Literally shell limestone; the middle member of the triassic system as it occurs in Germany.

MUSCITES (Lat. *muscus*, moss).—A general term for fossil plants of the Moss family, which as yet have been found only in amber and in certain fresh-water tertiary strata.

MUSCOVY GLASS.—A familiar term for *mica*,—most of the large plates used in the arts being brought from Eastern Russia, where they are employed as a substitute for glass.

MUSSEL-BIND or MUSSEL-BAND.—A miner's name for thin shelly bands, calcareous and ferruginous, that occur in the coal-measures. They are almost entirely composed of shells, resembling the fresh-water mussel, or *unio*.

MYLODON (Gr. *mylos*, a mill, and *odous*, tooth).—A gigantic edentate animal from the upper tertiaries of South America; and so called in allusion to the flat grinding surfaces of its molar teeth

N

NAGELFLUE or NAGHELFLUE.—A Swiss term for a soft arenaceo-calcareous conglomerate occurring among the tertiary strata of the Alps.

NAPHTHA.—A variety of bitumen (which see), thin, volatile, fluid, and highly inflammable. Springs of it exist in many volcanic countries—the finest variety being obtained from the shores of the Caspian, where it rises from calcareous rocks in the state of an odorous inflammable vapour. Naturally it is of a yellowish colour, but may be rendered colourless by distillation. Its specific gravity is about .75; it boils at 160 degrees; and appears to be a pure hydrocarbon—100 parts consisting of about 88 carbon and 15 hydrogen. Most of the naphtha of commerce is obtained by distillation from coal-tar, or directly from coal.

NAUTILITES.—A general term for fossil shells apparently allied to the existing nautilus. They occur in all formations from the silurian upwards (*clymenia*, *lituites*, *nautilus*, &c.); and are distinguished from ammonites by their central siphuncle, their simple sutures, and fewer whirls.

NEOCOMIAN.—A term of D'Orbigny's for the greensand formation, which is specially developed in the vicinity of Neufchatel (Neocomum).

NEOGENE (Gr. *neos*, new, and *ginomai*, I am formed).—The pliocene and miocene tertiaries are grouped together by some Continental geologists under the term *Neogene* (new-born), in contradistinction to the decidedly older strata of the Eocene.

NEOZOIC (Gr. *neos*, new, and *zoë*, life).—Arranging the fossiliferous strata into two great categories—the *palæozoic* and the *neozoic*—the former includes all up to the close of the permian, the latter all from the trias up to the existing order of things. It thus embraces the mesozoic and cainozoic of some palæontologists.

NEPTUNIAN (*Neptunus*, god of the sea).—Applied to stratified or aqueous rocks in contradistinction to *Plutonic* or igneous.

NEW RED.—A brief expression for the new red sandstones (permian and triassic) which occur above the coal-measures, in contradistinction to the old red which lies below.

NIPADITES.—A genus of fossil palm-nuts, found by Dr Bowerbank in the tertiary clays of the Isle of Sheppey, near London; and so called from their resemblance to the *Nipa fruticens* of Bengal and the East India Islands.—See fig., Tertiary System.

NODULE.—Any irregular concretion of rock-matter collected by attraction or aggregation round some central nucleus, as nodules of ironstone, flint, &c.

NÖGGERATHIA.—A genus of flabelliform palm-like leaves found in carboniferous and permian strata; so named after M. Nöggerath, who has done much for the elucidation of our fossil floras.—See fig.

NOTOPOCORYSTES (Gr. *notos*, the back; carapace).—A genus of cretaceous crabs, whose carapaces (the only portions yet definitely known) appear to have some relations with the existing genus *Corystes*.

NOTORNIS (Gr. *notos*, the south, and *ornis*, bird).—Literally "southern bird;" a short-winged rail or coot, first known by its sub-fossil bones found in the sands and volcanic debris of New Zealand, and believed to be extinct; but

subsequently one or two living specimens have been obtained.

NOTOTHERIUM (Gr. *notos*, the south, and *therion*, beast).—An extinct genus of gigantic quadrupeds found in the alluvial or upper tertiary deposits of Australia. As far as the teeth, jaws, and other scattered bones enable the comparative anatomist to decide, the *nototherium* manifests pachydermal modifications of the marsupial type; hence the inference that Australia (whose largest native quadruped is now the kangaroo) was, immediately preceding the current era, inhabited by a marsupial vegetable-feeder as large as the rhinoceros.

NUCLEUS (Lat. *nux*, a nut, *nucleus*, the kernel).—The solid centre of any nodule or rounded mass is said to be its nucleus; the centre round which any matter is collected or aggregated.

NUMMULITE (Lat. *nummus*, a coin, and *lithos*, stone).—A many-celled foraminiferous organism of the lower tertiary epoch; so called from its thin lenticular shape, or coin-like appearance.—See fig.

O

OBSIDIAN (Gr. *opsianus*, from being used for looking-glasses).—A glassy lava almost indistinguishable from artificial glass-slag. It consists of silica and alumina, with a little potash and oxide of iron, and is a true volcanic glass, of various colours, but usually black and nearly opaque.

OCHRE.—A very fine clay (silica and alumina) or powder of clay, coloured by oxide of iron, from yellow to deep orange. In the purer varieties there is merely a trace of clay, and the mass becomes a hydrated peroxide of iron—generally the result of decomposition.

ODONTOPTERIS (Gr. *odous*, *odontis*, tooth, and *pteris*, fern).—A somewhat obscure genus of fossil ferns occurring in the coal-measures, and so called from the blunt tooth-like lobes of their leaflets. In *Odontopteris* the leaves are bi-pinnated; leaflets lobed, membranous, adhering by all their base to the rachis, and furnished with a very indistinct midrib, from which a few ill-defined branching or simple veins pass into the lobes, which have no midrib.—See fig.

OGYGIA.—A species of silurian trilobite; so named in allusion to the obscure and remote character of these fossils. The name is derived from Ogyges, the earliest of the Grecian monarchs; *ogygian* being applied to everything of dark or doubtful origin and antiquity.

OLDHAMIA.—A peculiar sertularian-like zoophyte, or perhaps polyzoon, occurring in the lowest silurian or cambrian rocks, and so termed because first detected by Professor Oldham in the purplish hard schists of Bray Head, near Dublin.—See fig.

OLD RED.—A brief expression for old red sandstone in contradistinction to new red—the former lying beneath, and the latter above the coal-measures. *See* Devonian.

OLIGOCENE (Gr. *oligos*, small, and *kainos*, recent).—A term employed by Beyrich to designate certain tertiary beds of Germany (Mayence, &c.), which appear to be neither exactly eocene nor of miocene age, but to occupy an intermediate position.

OLIGOCLASE (Gr. *oligos*, small, and *klasis*, fracture).—A mineralogical term for soda felspar, in allusion to its peculiar fracture as distinguished from orthoclase.

OLIVINE.—An olive-coloured semi-transparent mineral occurring in rounded grains and crystals in many basalts and lavas.

ONCHUS (Gr. *onchus*, bent, or hooked like a talon).—According to Agassiz, a genus of cestracionts found in silurian, devonian, and carboniferous strata. Their fin-spines or dorsal-rays are the only portions known, and these derive their name from their talon-like shape—broad at the base, striated, bent backwards, and tapering to a point.

OOLITE (Gr. *oon*, egg, and *lithos*, stone).—Limestone composed of small rounded particles like the eggs or roe of a fish; hence also called *roestone*. The name of an important stratified system, in which limestones of this nature are characteristic beds. This *oolitic* texture is common to many calcareous sandstones and grits, as well as to the oolite proper, from which the name is derived.

OPAL.—A mixed siliceous mineral, allied to agate and calcedony, but distinguished by its peculiar resinous lustre. There are many varieties, as precious opal, common opal, semi-opal, wood-opal, &c.

OPALESCENT.—Resembling opal in lustre; displaying a play of colours like some varieties of opal.

OPHIOLITE and OPHITE (Gr. *ophis*, a serpent, and *lithos*, stone).—Synonymes of serpentine; but seldom used by British geologists.

ORNITHICHNITES (Gr. *ornis*, *ornithos*, a bird, and *ichnon*, a footprint).—The footprints of birds found chiefly on slabs of the trias, and supposed to belong to cursorial or grallatorial genera.

ORNITHOLITES (Gr. *ornis*, bird, and *lithos*, stone).—The general term for the remains of birds occurring in a fossil state.

ORTHOCERAS, ORTHOCERATITE (Gr. *orthos*, straight, and *keras*, horn). — A genus of straight horn-shaped chambered shells, occurring in several systems.

ORTHOCLASE (Gr. *orthos*, straight, and *klasis*, fracture).—A mineralogical term for potash felspar, because of its straight, flat cleavage.

ORYCTOLOGY (Gr. *oryktos*, dug up, and *logos*, doctrine).—The science of fossils; synonymous with Palæontology, but seldom used.

OSITE (Lat. *os*, a bone).—A term proposed by Dr Leidy of Philadelphia for the *Sombrero guano*, which appears to be a mass of altered bones of turtles and other marine animals, which had originally been collected on a shoal, and subsequently elevated into the existing islet of Sombrero, West Indies.

OSSEOUS BRECCIA (*os*, a bone).—Bones and fragments of bones cemented together by calcareous or other matter, and found in caverns and fissures, are so termed. *See* Breccia.

OSSIFEROUS (Lat. *os*, a bone, and *fero*, I yield).—Containing or yielding bones, as many of the post-tertiary sands and gravels.

OUTCROP.—The edge of any inclined stratum when it comes to the surface of the ground is called its *outcrop*, crop, basset, or basset-edge.

OUTLIERS. — Portions of any stratified group which lie detached from the main body; in general the result of denudation.

P

PACHYDERMATA (Gr. *pachys*, thick, and *derma*, skin). — Thick-skinned mammalia, as the elephant and rhinoceros among living species; and the mastodon, palæotherium, &c., among extinct tertiary races.

PALÆONTOLOGY (Gr. *palaios*, ancient, *onta*, beings, and *logos*, doctrine). — The science of fossil remains; the botany and zoology of the forms found fossil in the crust of the earth. It has been proposed to subdivide the science into Palæophytology, or fossil botany, and Palæozoology, or fossil zoology; but these terms are rarely used. *See* also Oryctology.

PALÆOTHERIUM (Gr. *palaios*, ancient, and *therion*, animal).—A pachydermatous mammal of the eocene tertiaries, somewhat akin to the existing tapir.—See fig.

PALÆOZOIC (Gr. *palaios*, ancient, and *zoë*, life).—The lowest division of stratified groups as holding the most ancient forms of life, in contradistinction to the *mesozoic* and *cainozoic*.

PALAGONITE (from Palagonia in Sicily). —A peculiar rock-product occurring in connection with modern volcanoes. The palagonite-tufa of Iceland is composed of silica, alumina, and lime, with iron, magnesia, potash, and soda, and is partially soluble by the hot water of the Geysers.

PALMACITES (Lat. *palma*, the palm-tree). —The general term for any fossil stem, leaf, fruit, or other organism, which presents some analogy or resemblance to one or other of the existing palms.

PAPER-COAL (Ger. *papier-kohle*). — A name given to certain layers of the tertiary lignites from their papery or leaf-like composition. They are evidently masses of compressed leaves. When taken fresh from the beds, the venation and reticulations of many of the leaves are quite apparent.

PECOPTERIS (Gr. *peko*, I comb, and *pteris*, fern).—*Comb-fern*. An extensive genus of fossil ferns occurring abundantly in the coal-measures, less numerously in the new red sandstone and oolite, and sparingly in cretaceous and lower tertiary strata. It derives its name from the regular comb-like arrangement of its leaflets; and is characterised by the leaves being once, twice, or thrice pinnate, and by the leaflets having a perfect midrib, from which forked veins proceed more or less at right angles with it.—See fig., Coal Formation.

PEGMATITE (Gr. *pegma*, compacted or congealed).—A binary granite composed of quartz and felspar—the felspar crystals lying in the quartz as in a matrix.

PELAGIC (Gr. *pelagos*, the deep sea).—Formed or deposited in deep sea, as distinct from littoral or estuary.

PELOROSAURUS (Gr. *pelorus*, monstrous, and *saurus*, lizard).—A huge amphibious reptile of the wealden epoch.

PEPERINO.—An Italian term for a light porous species of volcanic rock, formed, like tufa, by the cementing together of sand, scoriæ, cinders, &c.

PETRIFY, PETRIFACTION (Lat. *petra*, a stone, and *fio*, I become).—Literally to convert or change into stone. When a shell, bone, or fragment of wood, by being enclosed in mud or other sedimentary matter, becomes hard and stony, it is said to be petrified. Petrifaction is thus caused by the particles of stony matter entering, while in solu-

tion, into the pores of the vegetable or animal tissue, and as the organic matter disappears, gradually taking its place.

PETROLEUM (Lat. *petra*, rock, and *oleum*, oil).—A liquid mineral pitch, so called from its oozing out of certain strata like oil.

PETROSILEX.—Literally flint-rock. A synonyme of hornstone, though sometimes applied to the harder kinds of compact felspar.

PETWORTH MARBLE.—A limestone of the Weald; called also "Sussex marble." It is almost entirely composed of the shells of paludina, a well-known fresh-water univalve.

PHASCOLOTHERIUM (Gr. *phaskolos*, pouch, and *therion*, animal).—A marsupial quadruped of the oolitic period.

PHONOLITE (Gr. *phonos*, sound, and *lithos*, stone).—A species of basaltic greenstone; so called from its ringing metallic sound when struck by the hammer. Same as Clinkstone.

PINITES (Lat. *pinus*, the pine-tree).—The generic term for all fossil wood that exhibits structural approximations to the coniferous order; undoubted coniferous remains being ranked under the term *Peucites*. Remains of both occur in the coal-measures and upwards; but the existing genus *Pinus* has not been found earlier than in pleistocene or upper tertiary deposits.

PISIFORM (*pisum*, a pea).—Occurring in small concretions like pease; *e. g.*, Pisiform Iron-ore.

PISOLITE (*pisum*, a pea, and *lithos*, stone).—A concretionary limestone resembling an agglutination of pease. When the concretions are small, the rock is termed "roestone" or "oolite."

PITCHSTONE.—A glassy rock of the trappean division; so called from the pitchy lustre of its fracture.

PLACOID, PLACOIDEAN (Gr. *plax*, a plate, and *eidos*, form).—One of the orders of fishes, as arranged by M. Agassiz. The placoids are covered with irregular plates of enamel, and these frequently furnished with thorny tubercles. All the cartilaginous fishes, with the exception of the sturgeon, belong to this order.

PLAGIAULAX, an abbreviation for PLAGIAULACODON (Gr. *plagios*, oblique, *aulax*, groove, and *odous*, tooth).—A small herbivorous marsupial whose teeth and jaws have been found in the Purbeck beds of the oolite; and so named in reference to the diagonal grooving of the premolars. See fig.

PLAGIOSTOMA (Gr. *plagios*, oblique, and *stoma*, the mouth).—A generic term applied to certain compressed, obliquely oval bivalves of the oyster family, which are found fossil from the trias upwards. They are now ranked under the synonyme *Lima*, and partly under *Spondylus*.—See fig., Oolitic System.

PLANERKALK or PLANERKALKSTEIN, the German term for the upper member of the chalk formation in Saxony—our white chalk.

PLASTIC CLAY.—One of the lowest members in the London tertiary basin; so called from its use in the manufacture of pottery, &c. (Gr. *plasso*, I fashion or fabricate).

PLATYSOMUS (Gr. *platys*, broad, and *omos*, shoulder).—A ganoid fish of the carboniferous and permian epochs, and so called from its deep bream-like body.—See fig., Permian System.

PLEIOCENE (Gr. *pleion*, more, and *kainos*, recent).—Sir C. Lyell's term for the upper tertiary group, as containing more of recent than of extinct species. *See* Eocene.

PLEISTOCENE (Gr. *pleistos*, most, and *kainos*, recent).—A term used as synonymous with Post-tertiary, and implying that the organic remains in such accumulations belong almost wholly to existing species.

PLESIOSAURUS (Gr. *plesios*, near to, and *saurus*, lizard).—A marine reptile of the oolite; so called from its being more nearly allied to reptiles than the ichthyosaurus.—See fig.

PLEURODONT (Gr. *pleuron*, the side, and *odous*, tooth).—A term applied by Professor Owen to those inferior or squamate saurians which have the teeth anchylosed to the bottom of an alveolar groove, and supported by its side. *See* Thecodont.

PLEUROTOMARIA (Gr. *pleuron*, side, and *tomè*, notch).—An extensive genus of fossil shells belonging to the gasteropod family of the *Haliotidæ*. The shell resembles the *trochus*, is solid, few whirled, has its surface variously ornamented, and has a deep slit or notch in the outer margin of its somewhat square aperture. There are several hundred species, ranging from the silurian to the chalk inclusive.—See fig., Devonian System.

PLIOSAURUS (Gr. *pleion*, more, and *saurus*, lizard).—A marine reptile of the oolite, intermediate between the plesiosaur and ichthyosaur.

PLUMBAGO (Lat. *plumbum*, lead).—One of the names given to graphite, or black-lead, from its resemblance to an ore of lead. *See* Graphite.

PLUTONIC (Pluto, the god of the inferior regions).—Igneous rocks formed at some depth below the surface of the land or sea, as distinct from *Volcanic*, or those thrown up to the surface.

POACITES (Lat. *poa*, the meadow-grass).—The generic term for all fossil monocotyledonous leaves, the veins of which are parallel, simple, of equal thickness,

and not connected by transverse bars.

POLYPE (Gr. *polys*, many, and *pous*, foot).—The zoological term applied to zoophytes having many tentacula or foot-like organs of prehension; hence also the term *polypidom* (*domus*, a house), for the stony or coralline structure they inhabit.

POLYZOA (Gr. *polys*, many, *zoa*, animals).—This term embraces all the minute mollusca or molluscoids that inhabit compound phytoidal structures like the *flustra* and *retepora*, and which were, till lately, confounded with the polypes or corallines; known also as *Bryozoa*, which see.

PORPHYRY (Gr. *porphyreos*, purple).—This term was originally applied to a reddish igneous rock found in Upper Egypt, and used for sculptural purposes. It is now employed by geologists to denote any rock (whatever its colour) which contains imbedded crystals distinct from the main mass or matrix. We have thus, felspar porphyry, clay-stone porphyry, porphyritic granite, and porphyritic greenstone.

POTERIOCRINITES (Gr. *poterion*, a goblet, and *encrinite*).—A genus of encrinites occurring in the mountain limestone; so called from the vase or goblet shape of its body.

POTSTONE.—A soft magnesian rock, sectile, and capable of being fashioned into pots and vases; the *lapis ollaris* of the ancients.

POZZUOLANA (from Pozzuoli, in the Bay of Naples).—A volcanic ash used in the manufacture of Roman cement.

PRIMARY, PRIMITIVE.—Applied by the earlier geologists to non-fossiliferous rocks, such as gneiss and mica-schist, from the belief that they were first-formed (*primus*, first), or deposited before the creation of life on our globe. Equivalent to Hypogene or Azoic.

PRIMORDIAL.—A term used by M. Barrande for the lowest or earliest zone of fossiliferous strata. Same as Cambrian of Sedgwick.

PROTOGINE (Gr. *protos*, first, and *ginomai*, I am formed).—The French term for a granite composed of felspar, quartz, and talc; not very happily chosen.

PROTOZOA (Gr. *protos*, first, and *zoë*, life).—In modern systems of classification the *first* or lowest division of the animal kingdom. It includes a number of creatures of a very lowly type of organisation, and which appear almost to occupy a sort of neutral ground between animals and vegetables. It embraces the *Rhizopods*, to which the foraminifera belong: the *Porifera*, or sponges; and the *Infusoria*.

PROTOZOIC (Gr. *protos*, first, and *zoë*, life).—The strata containing the earliest traces of life; equivalent to Primordial.

PSAROLITES or PSARONITES (Gr. *psaros*, speckled, and *lithos*, stone).—The name given to the silicified stems of tree-ferns found abundantly in the new red sandstone of Hillersdorf, in Saxony, in allusion to the stellated markings produced by sections of the vessels composing their tissues. The *Staarenstein* or starstone of the Germans.

PTERODACTYLE (Gr. *pteron*, wing, and *daktylos*, finger).—A flying reptile of the mesozoic epoch, with one elongated wing-finger.—See fig.

PTEROPHYLLUM (Gr. *pteron*, a wing, and *phyllon*, leaf).—Literally "wing-leaf;" a genus of cycadaceous leaves, chiefly from the lias and oolite. Like ferns, they are pinnated, but are readily distinguished by their greater substance, thicker midrib, and especially by *their veins being in all cases undivided;* that is, never forking or dichotomising as in ferns.—See fig.

PTERYGOTUS (Gr. *pteryx*, a wing, and *ous*, *otos*, the ear).—A gigantic crustacean of unknown affinity, belonging to the dawn of the old red sandstone period. So called from the peculiar shape of its detached mandibular or jaw-feet, which were at first mistaken by Agassiz as the remains of some fish. It has been found chiefly in Forfar and Hereford shires.—See fig.

PTYCHOCERAS, PTYCHOCERATITE (Gr. *ptyche*, a fold).—A genus of chambered shells of the ammonite family, characteristic of the chalk formation, and so called from the shape of the shell, which is bent or folded upon itself—the two straight portions being in contact.

PUDDINGSTONE.—Now used as synonymous with Conglomerate, but originally applied to a cemented mass of flint pebbles, from the resemblance of the imbedded pebbles to the fruit in a plum-pudding.

PULVERISE (Lat. *pulvus*, *pulveris*, dust).—To reduce to dust or powder; to crumble. Soil and rocks crumbled down by aqueous or atmospheric agency are said to be pulverised.

PUMICE (Ital. *pomice*, akin to *spuma*, froth).—A light spongy lava; volcanic froth or scum.

PYCNODONTS (Gr. *pyknos*, thick, and *odous*, *odontos*, tooth).—Literally thick-teeth; an extensive family of fishes occurring in mesozoic strata. Their leading character consists in having the mouth provided with a dense pavement of thick, round, and flat teeth, for the purpose of crushing the shells and crustacea on which they fed.

PYRITES (Gr. *pyr*, fire, and *ites* for *ithos*).—Sulphurets of iron, copper, &c., are

so termed, either from the hardness of iron pyrites, which strikes fire, or from its decomposing spontaneously with a considerable evolution of heat.

PYROGENOUS (Gr. *pyr*, fire, and *ginomai*, I am formed).—Fire-formed; used as synonymous with *igneous*.

PYROXENE (Lat. *pyr*, fire, and *xenos*, strange).—A name used by Continental mineralogists for *augite*.

Q

QUADERSANDSTEIN (Ger.)—Literally "square-stone or freestone;" a member of the German chalk formation, apparently the equivalent of our upper greensand.

QUADRUMANA (*quatuor*, four, and *manus*, hand).—Literally four-handed; applied to the monkeys and lemurs.

QUAQUAVERSAL.—Dipping on every side; applied to strata that dip on all sides from a common centre.

QUARTZ.—A German miner's term for crystallised silica; rock-crystal; silica in its purest rock-form.

QUARTZITE.—An aggregation of quartz grains; granular quartz. This term is generally applied to sandstones which have been indurated or altered by heat so as to assume the aspect of quartz rock.

QUATERNARY (Lat. *quatuor*, four).—Applied to all accumulations above the true tertiaries; equivalent to Post-tertiary.

R

RADIOLITES.—A genus of cretaceous bivalves belonging to the curious *Hippurite* family, and so called from the radiated structure of the outer layer of its opercular-looking upper valve. The under valve is large, inversely conical, and rough and foliaceous outside; the upper valve is convex or sub-conical, and so small in proportion as to look like an operculum rather than true valve.—See fig.

RAG, RAGSTONE.—A provincial English term for any coarse concretionary or breccio-concretionary siliceous rock, as "Kentish rag," "Rowley rag," &c.

REDDLE.—A provincial term for a red argillaceous ore of iron; also called *red-clay*, and *red-chalk*. It is simply decomposing hæmatite.

RENIFORM (Lat. *ren*, kidney).—Applied to kidney-shaped concretions of ironstone, limestone, &c.

RHYNCOLITES or RHYNCHOLITES (Gr. *rhynchos*, a beak, and *lithos*, stone).—The fossil beak-like mandibles of cephalopods (like the cuttle-fish and nautilus) which generally occur detached in the lias, oolite, and chalk formations.

RHYNCHOSAURUS (Gr. *rhynchos*, beak, and *sauros*, lizard).—Literally "beak-saurian;" a remarkable genus of saurians from the new red sandstone of Warwickshire, combining the lizard type of skull with toothless jaws, and so termed from the long, downward-curving intermaxillary bones, which impart to the fore part of the head a beak-like aspect.—See fig.

ROCKING-STONES.—Weather-worn rounded blocks, generally of granite or tabular greenstone, so nicely poised on their basis that a very ordinary force suffices to make them oscillate or "rock" from side to side.

ROCK-SALT.—Common salt, when found in rock masses, as in Cheshire, is thus termed.

ROTH-TODTE-LIEGENDE.—Literally "red-dead-liers;" the name given by German miners to the red sandstones and marls which lie under the kupfer-schiefer or copper-slate, because they are "dead" or non-metalliferous.

ROTTENSTONE.—A siliceous and aluminous compound resulting from the decomposition of impure limestones by the percolation of carbonated waters.

RUBBLE.—A quarryman's term for the loose covering of angular fragments which appears at the outcrop of many sandstones. Applied also to all accumulations of loose angular fragments not water-worn and rounded like *gravel* and *shingle*.

S

SACCHAROID (*sacchar*, sugar, and *eidos*, form).—Resembling loaf-sugar in texture; applied to crystalline limestones.

SADDLE-BACK.—A familiar term for anticlinal strata, which see.

ST CUTHBERT'S BEADS.—A north-of-England term for the separate bead-

like joints of the encrinite, from a legend alluded to by Sir Walter Scott in *Marmion*—

"On a rock, by Lindisfarne,
St Cuthbert sits, and toils to frame
The sea-born beads that bear his name."

SALIFEROUS (Lat. *sal*, salt, and *fero*, I yield).—Containing or yielding salt, as "saliferous strata," "saliferous deposits," &c. *Saliferous system* is often used as synonymous with Upper New Red Sandstone, which is the great repository of rock-salt in England.

SALINE (*sal*, salt).—Containing or impregnated with salt, as "saline" springs.

SAURIANS (Gr. *sauros*, a lizard).—Lizard-like scaly reptiles like the existing lizards, monitors, iguanas, chameleons, &c., and the fossil iguanodons, ichthyosaurs, plesiosaurs, &c. *Sauroid*, like or akin to saurians.

SCALARIFORM (Lat. *scalaris*, a ladder, and *forma*, form).—Presenting the appearance of a ladder; applied by botanists and microscopists to certain vessels in the woody structure of the cycads and conifers having an elongated form, and crossed by connecting fibres, like the steps of a ladder.

SCAPHITE (Lat. *scapha*, a skiff). — A chambered shell of the chalk formation; so termed from its boat-like contour, its inner whorls looking like an ancient reversed prow.

SCAR.—A bluff precipice of rock; hence "scar-limestone," applied to the mountain limestone as it occurs in the hills of Yorkshire and Westmoreland.

SCHILLER-SPAR (Ger. *schillern*, to change colour).—A magnesio-siliceous mineral, having a pearly metallic lustre, flat cleavage, and exhibiting a slight play of colour. *See* Diallage.

SCHIST (Gr. *schisma*, a splitting or division).—This term should be restricted to such rocks as mica-schist, gneiss, and the like, which have a foliated structure, and split up in thin irregular plates, not by regular cleavage as in slate-rocks.

SCHLERODUS (Gr. *schleros*, rough, and *odous*, tooth.—A genus of fishes found in the Ludlow bone-bed, and so named from the raised postules on the surface of their teeth.

SCHORL or BLACK TOURMALINE.—A prismatic longitudinally striated mineral, occurring abundantly in granitic rocks.

SCOLITHUS or SCOLITES (Gr. *skolios*, tortuous), applied to those tortuous tube-like markings which occur in certain sandstones, and which seem to have been the burrows of annelids.—See fig.

SCORIÆ (Ital. *scoria*, dross).—Applied to all accumulations of dust, ashes, cinders, and loose fragments of rock discharged from volcanoes.

SEAM. — Strictly speaking, the line of separation between two strata, but loosely applied to subordinate strata, occurring in any series, as *seams of coal* in the coal-measures.

SECONDARY STRATA.—Originally applied to the fossiliferous strata lying between the transition and tertiary. Same as Mesozoic.

SECTION (Lat. *sectus*, cut through).—The plane, actual or ideal, which cuts through any portion of the earth's crust so as to show the internal structure of that portion. *Natural* sections are exhibited by sea-cliffs, sides of ravines, &c.; *artificial* ones by road and railway cuttings, wells, and coal-pits.

SEDIMENT (Lat. *sedere*, to settle down).—Matter settled down from suspension in water. If the turbid muddy waters of a river be allowed to stagnate, the mud will gradually fall to the bottom and form sediment. Rocks which have been formed in this manner, as shale, clay, sandstone, &c., are termed *sedimentary*.

SELENITE (Gr. *selenè*, the moon).—Crystallised sulphate of lime; so galled from its subdued lustre and transparency.

SEPTARIA (Lat. *septum*, a fence or division).—Nodules of clay, ironstone, or other matter, internally divided into numerous angular compartments by fissures which are usually filled with calcareous spar.

SERIES.—Applied to a number of allied objects arranged in sequence, as the greensand series, Wenlock series, &c.

SERPENTINE. — A siliceo-magnesian rock of granitic or metamorphic origin; so called from the resemblance of its mottled colours to the skin of a serpent.

SHALE (Ger. *schalen*, to peel or shell off).—Applied to all argillaceous strata that split up or peel off in thin laminæ. *Clay* is massive or plastic; *marl* is friable or crumbly; *shale* occurs in leaf-like laminæ.

SHINGLE. — Loose, imperfectly rounded stones and pebbles, as distinct from gravel and sand.

SIGILLARIA (Lat. *sigillum*, a seal).—An extensive genus of fluted tree-stems characteristic of the carboniferous system, and so named from the seal-like punctures (leaf-scars) which occur on the ridges or raised flutings of their stems.—See fig.

SILICEOUS (Lat. *silex*, flint).—All rocks having a flinty texture are said to be siliceous. Rock-crystal and quartz are the purest states in which *silex* occurs in nature; common flint is an impure variety.

SILICEOUS SINTER (*see* Sinter).—A siliceous incrustation or deposit from springs holding silica in solution, like the Geysers of Iceland.

SILICIFIED (Lat. *silex*, flint, and *fio*, I am

made).—Converted into flinty or siliceous matter; petrified by the infiltration of silica.

SILT is properly applied to the fine impalpable mud which collects in lakes and estuaries, but is generally used to designate all calm and gradual deposits of mud, clay, or sand.

SINTER (Ger. *sintern*, to drop).—Compact incrustations from siliceous or calcareous springs are known as siliceous sinter and calc-sinter. The term is applied in contradistinction to tuff or tufa, which is open and porous.

SLATE.—This term should be restricted to argillaceous rocks, like roofing-slate, whose lamination is not produced by lines of bedding, but is due to a metamorphism called *cleavage*, which often runs at right angles to the line of stratification.

SLICKENSIDES.—In mining, the smooth striated surface of a fault or fissure, apparently produced by convulsive friction, and subsequently coated with a siliceous or calcareous glaze by the passage of water or heated vapours. Also provincially applied to an ore of galena occurring in Derbyshire.

SOAPSTONE.—A soft sectile variety of steatite; so called from its soapy feel.

SOLFATARA (Ital. *solfo*, sulphur).—A volcanic fissure or orifice from which sulphureous vapours, hot mud, and steam, are emitted.

SPAR (Ger. *spath*).—A mineralogical term applied to those crystals or minerals which break up into rhombs, cubes, plates, prisms, &c., with smooth cleavage-faces. Hence we have calc-spar, felspar, brown-spar, &c.

SPLINT or SPLENT COAL.—A Scotch term for a hard laminated variety of coal intermediate between cannel and common pit-coal.

SPORE, SPORULE (Gr. *spora*, seed).—The reproductive germ of cryptogamic plants, as the fern and club-moss.

STALACTITE (Gr. *stalasso*, to drop).—Applied to those icicle-like incrustations of lime, calcedony, &c., which often fret the roofs of caverns and fissures, and which arise from the dropping of water holding these rock-matters in solution.

STALAGMITE (Gr. *stalagma*, a drop).—The same mineral matter as stalactite, but applied to the incrustation that covers the floor of the cavern. The stalactites and stalagmite frequently meet each other, and form pillar-like masses in limestone caverns.

STEATITE (Gr. *stear*, fat).—A soft magnesian rock having a smooth soapy feel; Soapstone.

STIGMARIA (Lat. *stigma*, a dot or puncture).—An extensive assemblage of root-stems characteristic of the carboniferous system, and so named from their regularly pitted or dotted surface—each puncture representing the attachment of a long slender fleshy radicle. Stigmaria are the roots of *sigillaria*.—See fig.

STINKSTONE (Ger. *stinkstein*).—A name given to fetid limestones—that is, those which, on being struck or rubbed, emit an odour of sulphuretted hydrogen.

STRATUM, plural STRATA (Lat. *stratum*, strewn or spread out).—When rocks lie in layers, one above another, each layer forms a *stratum*, the whole a series of *strata*. Rocks lying in parallel layers are said to be *stratified*; those among which there is no appearance of this arrangement, *unstratified*. Layer, bed, seam, band, &c., are less or more used as synonymous with stratum.

STRIATED (Lat. *stria*, a streak).—Streaked or marked with fine thread-like lines running parallel to each other.

STRIKE.—The direction or line of outcrop of any stratum. The strike of a stratum is at right angles to its dip.

STYLONURUS (Gr. *stylos*, a writing-style, and *oura*, the tail).—A crustacean of the lower old red, exhibiting a form intermediate between the xiphosurus and phyllopod families.—See fig.

SUB, SUB-CRYSTALLINE, SUB-COLUMNAR, &c.—In Geology the term *sub* (under) is employed to denote a less or inferior degree; as sub-crystalline, less than crystalline; sub-columnar, not distinctly columnar, &c. It also applies to position, as sub-cretaceous, under the chalk; sub-aqueous, under the waters, &c.

SUB-APENNINES.—An extensive suite of older and newer pliocene beds, which are amply developed along the whole extent of Italy on both flanks of the Apennines, and forming a line of low hills between the older chain and the sea.

SURTUR-BRAND.—An Icelandic term for a peat-like variety of brown coal or lignite occurring in the pliocene deposits, and sometimes under the volcanic overflows of that island.

SUSSEX MARBLE.—A shell limestone of the wealden formation; so called from being found in Sussex. *See* Petworth Marble.

SYENITE (from *Syene*, in upper Egypt).—A granitic rock composed of felspar, quartz, and hornblende.

SYNCLINAL (Gr. *syn*, together, and *clino*, I bend).—Applied to strata that dip from opposite directions inwards, like the leaves of a half-opened book, or which incline to a common centre, forming a trough or basin-shaped hollow.

SYSTEM (Gr. *syn*, together, and *histemi*, to stand).—Groups of objects or occurrences having such relations as permit them to be classed together, constitute a system.

T

Tabular.—Composed of, or arranged in, square blocks or table-like masses, as many granites and greenstones. The tabular frequently passes into the columnar structure, and *vice versa*.

Talus.—The loose detritus accumulated at the base of cliffs and precipices, and derived from their weathered and wasted surfaces.

Taxites (Lat. *taxus*, the yew-tree).—The generic term for such coniferous remains as are evidently allied to the yew-tree. They occur in the oolite, but chiefly in the tertiary lignites.

Teleosaurus (Gr. *teleos*, complete, and *saurus*, a lizard).—A genus of crocodilian saurians belonging to the oolitic period, and distinguished by having, like the recent gavial, long tapering muzzles, armed with numerous pointed teeth, but differing in having the nasal apertures terminating in *two* orifices in front of the nose, and not blended into one opening, as in the recent species. Differ also, in having bi-concave instead of concavo-convex vertebræ.

Telerpeton (Gr. *tele*, afar off, remote, and *erpeton*, reptile).—A small lizard-like reptile from the triassic sandstones of Elgin formerly supposed to be of old red age, and so named in allusion (palæontologically speaking) to its remote antiquity.—See fig., Triassic System.

Tentaculites (*tentacula*, feelers; so called from their being stretched out when the animals possessed of them are in the act of exploring).—A genus of jointed feeler-like organisms occurring in silurian strata.

Tertiary.—The third or upper great division of the stratified systems, as distinguished from secondary and primary.

Tetrapodichnites (Gr. *tetra*, four, *pous*, *podos*, the foot, *ichnon*, a footprint, and *ites*).—The footprints of four-footed creatures, as batrachian reptiles and other terrestial saurians.

Thecodontosaurus (Gr. *thekè*, a sheath, *odous*, tooth, and *saurus*, lizard).—A permian saurian; so called from the sheath or cone-in-cone-like structure of its teeth.

Thelodus (Gr. *thelè*, a little nipple, and *odous*, tooth).—A fish of the silurian bone-bed; so called from its peculiar mammilated teeth. Nothing is yet known of its true affinities.

Thermal (Gr. *thermè*, heat).—Applied to hot springs and other waters whose temperature exceeds that of 60° Fahr.

Thuites.—A genus of coniferous plants occurring in fragments in the shale and coal of the oolite, and so called from the resemblance of their imbricated stems and terminal twigs to those of the modern *thuja* or *thuya*, better known as the *arbor-vitæ*.

Thylacotherium (Gr. *thylakos*, pouch, and *therion*, animal).—A marsupial mammal of the oolite. Same as amphitherium.

Tilestone.—Any thinly-laminated sandstone fit for roofing; applied specially to the flaggy beds at the base of the old red sandstone.

Toadstone.—Applied to certain earthy amygdaloids occurring in connection with the mountain limestones of Derbyshire. By some said to be from the German *todt-stein*, or dead-stone, as being dead or unfruitful of lead ore. According to others it derives its name from the resemblance of its amygdaloidal spots to those of a toad's back.

Touchstone.—A variety of *flinty-slate*; so called from its being used for testing the purity of gold—the quality of the metal being judged of by the colour of the streak which it leaves on the stone. *See* Lydian Stone.

Toxodon (Gr. *toxos*, a bow, and *odous*, tooth).—A large quadruped of unknown affinity, from the upper tertiary or Pampean formation of South America, and so named by Professor Owen from the singularly curved form of its two outer incisors.

Trachyte (Gr. *trachys*, rough).—A felspathic volcanic rock; so called from its harsh meagre feel.

Transition.—The passage from one state or period to another. Formerly applied to the older palæozoic strata, as indicating a transition from unfossiliferous to fossiliferous conditions.

Trap, Trappean (Swed. *trappa*, a stair). — Tabular greenstone and basaltic rocks, from their rising up in step-like masses, were originally so termed; but the name is now extended to all igneous rocks which are not either strictly granitic or decidedly volcanic. Others derive the origin of the term from the terrace-like aspect of secondary hills, generally composed of interstratified greenstones, basalts, amygdaloids, &c., which stand out in ledges from the softer strata that have yielded to denuding forces.

Trass or Tarass.—A provincial term for a tufaceous alluvium which occupies wide areas in the region of the Rhine. Its basis consists almost entirely of pumice, in which are included frag-

ments of basalts and other lavas, pieces of burnt shale, slate, sandstone, and numerous trunks and branches of trees.

TRAVERTINE.—A whitish concretionary limestone deposited from the water of springs holding lime in solution; abundantly formed by the waters of the Anio at Tibur, near Rome; hence the name Tiburtinus, Travertinus.

TRIGONIA (Gr. *treis*, three, and *gonè*, a corner).—A dimyarian bivalve of the oolite and chalk, so called from its three-cornered shape.—See fig.

TRIGONOCARPON (Gr. *treis*, three, *gonè*, corner, and *carpon*, fruit).—A three-cornered palm-like nut, of the coal-measures, of unknown affinity.

TRILOBITES (Gr. *treis*, three, and *lobos*, lobe).—Palæozoic crustacea, especially characteristic of silurian strata, so called from their three-lobed aspect.

TRIPOLI.—A polishing powder originally brought from Tripoli, but now found in many other places. It is a kind of rottenstone, composed of the siliceous shields of microscopic infusoria and diatomaceæ; an infusorial earth or rock.

TROGONTHERIUM (Gr. *trogo*, I gnaw, and *therion*, beast).—Literally "gnawing beast;" an extinct rodent found in the fresh-water pleistocene or uppermost tertiaries of Europe, and so closely allied to the existing beaver that it is by some palæontologists regarded as a mere specific or sub-generic form.

TUFA, TUFF (Ital. *tufo*, Gr. *tophos*).—Originally applied to a porous rock composed of cemented scoriæ and ashes, but now used for any porous vesicular compound, as calc-tuff, trap-tuff, volcanic tufa, &c.

U

ULODENDRON (Gr. *hulè*, a wood, and *dendron*, tree).—A genus of coal-measure trunks, often of considerable size, and characterised by their stems not being furrowed, but covered with rhomboidal scales, and having on opposite sides two vertical rows of large circular scars, to which cones had been attached.—See fig.

UNCONFORMABLE.—Strata lying parallel on each other are said to be *conformable*; but when one set is laid on the upturned edges of another, they are *unconformable*.

UNDERCLAY.—A term now generally applied to those argillaceous beds which immediately underlie seams of coal. These underclays are usually tenacious, more or less bituminous, and almost always interpenetrated by stigmaria roots. Every seam of coal has not an underclay; but where they exist they seem to have been the ancient soil or mud on which the vegetation of the coal-bed flourished.

UNSTRATIFIED.—Used as synonymous with igneous; rocks which do not occur in layers or strata, but in amorphous masses.

V

VARIEGATED SANDSTONE.—The new red sandstone of English geologists; *grès bigarré* of the French, and *bunter-sandstein* of the German.

VEIN (Lat. *vena*).—Applied in Geology to all fissures and rents filled with mineral or metallic matter differing from the rock-mass in which they occur.

VENTRICULITES (Lat. *ventriculus*, a ventricle or sac).—The name given to certain fossil zoophytes of the chalk, usually appearing as fungiform flints, and well known to the inhabitants of Kent and Sussex as "petrified mushrooms."—See fig.

VESICULAR (Lat. *vesicula*, a little bladder).—Applied to rocks full of little cavities, as vesicular lava, vesicular trap-tuff, &c.

VITREOUS (Lat. *vitrum*, glass).—Having the lustre or aspect of glass; glassy. *Vitrify*, to melt or convert into glass.

VOLCANIC (*Vulcanus*, god of fire).—Igneous action apparent at the surface of the earth, in contradistinction to *Plutonic* (which see), or that taking place at great depths in the interior. *Volcanic*, as applied to rocks, embraces all igneous products of recent or modern origin, as distinct from trappean and granitic.

VOLKMANNIA (after Volkmann).—A provisional genus of coal-measure stems having verticillate or whorled leaves, and bearing cones on their extremities. They are regarded as asterophyllites in fructification.

VOLTZIA (after Voltz of Strasburg).—A genus of coniferous plants peculiar to the permian and triassic formations. They greatly resemble araucaria in the form and imbrication of their leaves.—See fig.

VULCANISTS.—Applied to those geologists who opposed the Wernerian or Neptunian doctrine, that all rocks were of aqueous origin.

W

Wacke.—A German miner's term for a soft earthy variety of trap-rock.

Walchia (after Walch).—A genus of coniferous plants occurring in the carboniferous and permian systems. According to Sternberg, who erected the genus, they have numerous closely-set, regularly-pinnated branches, resembling those of *Araucaria excelsa*, and which are thickly beset with foliage.—See fig., Permian System.

Warp.—A provincial term for the muddy deposit from waters artificially introduced over low lands, as those adjoining the Trent, Ouse, &c.

Weald (Sax. *wold*, or woodland).—The low country lying between the North and South Downs of Kent and Sussex; and from this locality being the chief area of a formation that lies between the chalk and oolite, the term Wealden, or Weald, has been applied to the strata of that formation.

Wenlock Limestone.—A characteristic member of the upper silurian group.

Whin, Whinstone.—Used in Scotland as synonymous with greenstone; but applied by miners to any hard resisting rock that comes in their way.

Z

Zamites.—Fossil plants apparently allied to the existing zamia. They make their appearance in the upper oolites, and continue throughout the secondary and tertiary formations.—See fig.

Zechstein.—Literally mine-stone; a German term synonymous with our magnesian limestone—the copper-slate (kupfer-schiefer) being worked immediately beneath it.

Zygomaturus.—A large marsupial mammal—the most extraordinary yet discovered in the post-tertiary deposits of Australia, and so named from the great width of the zygomatic arches of the skull. Judging from the size of the head, which was the only portion found in 1858, it seems to have been as large as an ox, and to have had a face somewhat resembling that of the existing wombat.

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